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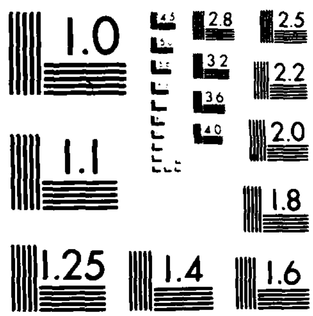

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ANALYTICAL PREDICTION OF PRESSURES AND FORCES ON A SHIP HULL DUE TO CAVITATING PROPELLERS

by

Paul Kaplan, James Bentson and Moshe Benatar

Prepared for

Department of the Navy
Office of Naval Research
800 N. Quincy Street
Arlington, Virginia 22217

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An existing technique for determining free space pressures generated by a cavitating propeller operating in a ship wake is used as the basic input for determining the pressure distribution on various ship sections. The procedure involves establishing a boundary value problem on the ship section and the free surface, with appropriate conformal mapping operations that allow conversion of the problem to a more simplified boundary, viz. a flat plate and its adjacent free sur-

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The solution provides the pressure distribution at different sections on the hull, from which the total forces are then determined via integration with this strip theory approach. In addition the effects of different mode shapes of hull vibration are incorporated in order to obtain generalized forces for determining hull vibration responses. Illustrations of results are given for a representative naval auxiliary vessel.

The effect of different section shapes and dimensions in establishing body solid boundary factors (relative to the free space pressure) is also demonstrated. An extension of the basic analysis is applied to the problem of a ship section with adjacent rigid boundaries on the free surface similar to the case of particular cavitation tunnel test facilities, thereby providing a method of evaluating boundary effects of laboratory test facilities relative to full scale flow conditions.

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INTRODUCTION

During the past 25 years extensive studies have been carried out, both theoretically and experimentally, relating to the bearing forces acting on a propeller in a ship wake as well as determining the free space hydrodynamic pressure generated by such a propeller in that operating mode. While most of these studies were initially concerned with propellers for which cavitation was not present, the occurrence of cavitation on the propeller has led to free space pressures that are an order of magnitude larger than those associated with the noncavitating propeller. The occurrence of cavitation is usually present in a limited angular region about the upright (i.e. 12 o'clock) position of the propeller blade as it encounters a wake field that varies significantly in that region. This large pressure due to cavitation results from the rapid growth and collapse of the cavity volume which begins in the region of the blade tips.

In view of the importance of this effect of cavitation which leads to these high pressures, and the interest by designers in various propeller modifications that could result in reduced tip clearance and changes in the local hull shape in proximity to the propeller, it is important to have a method that could predict the magnitude of the pressures as well as the forces acting on the ship hull due to the effects of the cavitation that may occur on the propellers under those conditions. Some work has been previously published (Kaplan et al, 1979) that allows determination of the vibratory hydrodynamic pressures arising from propeller cavitation, and that work has demonstrated a fair degree of success in prediction and correlation with a number of experimental measurements (both model and full scale). This particular tool can be used as a basic element to determine the extent of possible vibratory problems associated with design variations of propeller-hull form

configurations for different applications.

The method of (Kaplan et al, 1979) is primarily concerned with determining the basic free space pressures associated with the occurrence of cavitation. What is important for further practical utility would be a method that allowed accurate determination of the pressure distribution on various sections of a ship hull due to these cavitating propellers. The usual procedure has been to multiply the free space pressure by a factor of 2, reflecting the influence of a large flat boundary. Since all ship sections do not necessarily have such a characteristic, an appropriate analysis should be made to determine the proper pressure distribution on a ship section.

In addition to the determination of pressure per se, it is recognized that any vibration analysis would require determining the total forces acting on the ship hull due to the propeller-induced pressures. There are a number of different ways in which this can be done at present, either by solution of a diffraction problem as in the work of (Breslin and Eng, 1965) or by use of the reciprocity relations derived by (Vorus, 1974). Another possibility would be to integrate the pressure distribution along each section, if that information is available. Regardless of which way is considered for determining the force by any of the methods discussed above, an extensive degree of analysis and/or computation is necessary in order to determine the total forces with the present state-of-the-art.

The present report describes a technique for determining the pressure distribution at various ship sections as a function of the ship section geometry, using information on the free space pressure field due to a cavitating propeller in a wake. Another element of this work is a simple determination of the total force on different ship sections, from which the entire vibratory force can be evaluated. A description of the procedures that are used to obtain all of these results is given in the following sections of this report.

FREE SPACE PRESSURES, INCLUDING CAVITATION EFFECTS

Since the present work applies and extends the procedures developed by (Kaplan et al, 1979), some of the basic concepts used in that particular study are described here. The procedure in (Kaplan et al, 1979) initially makes use of an existing computer program and analysis (Tsakonas et al, 1976, 1977) developed at Davidson Laboratory to predict the blade forces acting on a non-cavitated propeller operating in a ship wake. The information on the radial distribution of blade forces from (Tsakonas et al, 1976) is used to establish values of local camber and angle of attack distributions along the propeller span. These quantities, which establish local propeller blade section inflow velocity, cavitation index, etc., are used to evaluate the cavitation quantities appropriate to a particular propeller and wake at each propeller section of interest by use of a two-dimensional quasi-steady model of cavity flow (Geurst and Verbrugh, 1959). The cavitation quantities of interest in this case are the section force coefficients (C_L, C_m, etc.) and the local cavity area for each section, which are found for conditions appropriate to partial cavitating flow ($\ell/c<1$, where ℓ = cavity length and c = chord length), supercavitating flow ($\ell/c<1$), and the important "transition" range between these two cavitation regions.

With the basic cavitation properties described above, the analysis of (Kaplan et al, 1979) establishes a general representation of the velocity potential and hydrodynamic pressure field associated with a time-varying cavity on a propeller blade. The expressions contain terms associated with the effect of changing thickness and loading of the propeller, as well as the important source-like contribution associated with the changing volume of the cavity on the propeller (obtained in terms of the distribution of cavity sectional area along the span of each propeller blade). The total free space pressure at any point is then found by

the sum of the terms corresponding to the cavitation effect (cavity source effect and loading) as well as the effects of the non-cavitating propeller found from (Tsakonas et al, 1977). In most practical cases the non-cavitating propeller contribution is essentially negligible in comparison with the contributions arising from cavitation.

The expression for the field pressure due to the cavity effect on the propeller is given in terms of variables related to the coordinate system shown in Figure 1, and is given by

$$p_c = \frac{\rho_f \Omega}{4\pi} \int_{r_c(\theta)}^{r_o} \left\{ \frac{1}{R^3} \frac{\partial A_c}{\partial \theta} \left[\bar{U}x - \Omega r \rho \left(1 + \frac{1}{2r} \frac{\partial \ell}{\partial \theta} \right) \cdot \sin \left[\theta + \sigma_s - \phi - \frac{(c-\ell)}{2r} \right] \right] \right.$$
$$\left. + \frac{\Omega}{R} \frac{\partial^2 A_c}{\partial \theta^2} \right\} dr \qquad (1)$$

In this expression R is the distance from any blade element to the field point; $\bar{U}$ is the mean axial velocity averaged over the propeller disc; r is the radial coordinate along the propeller blade; A_c is the cavity area; Ω is the propeller angular velocity; σ_s is the skew angle of the blade. The radiated field pressure due to the cavity can be seen to contain sources with strength proportional to $\partial^2 A_c/\partial t^2$ and dipoles (axial and transverse) with strength proportional to $\partial A_c/\partial t$, together with a dependence on the cavity length and its variation with time.

The field pressure due to the change in loading arising from cavitation is expressed by

$$p_\ell = -\frac{1}{4\pi} \int_{r_c}^{r_o} \frac{\partial}{\partial n} \left(\frac{1}{R} \right) \Delta L_{cav}(r,t)\ dr \qquad (2)$$

where the integration is carried out over the cavitated region on the blade. The quantity ΔL_{cav} is the change in lift of each radial section of the propeller blade due to cavitation, and the operation $\partial/\partial n$ represents the normal derivative relative to the helicoidal surface. The various operations to obtain the lift due to cavitation, the angle of attack, force coefficients, cavity characteristics, etc. used in

the evaluation of Eqns. (1) and (2) are described by (Kaplan et al, 1979).

The values of pressure due to cavity geometry variations (from Eqn. (1)) and pressure due to load changes due to cavitation (from Eqn. (2)) are added together to produce the total pressure due to cavitation for a single blade. This is evaluated as a function of time (or blade angle) during a single propeller rotation, and the resulting time history is then Fourier analyzed in terms of the shaft rate and higher harmonics. With proper allowance for relative blade phasing the total effect for the entire propeller is obtained by summing all the harmonic components, which results in final output pressure at the propeller blade rate and its harmonics.

The results obtained by this method (Kaplan et al, 1979) showed good agreement for measured point pressures on a ship hull, for both model and full scale conditions. The model test results were obtained in European research establishment water tunnels using simulated wakes and dummy stern regions, while full scale data was obtained from direct measurements at sea. In view of the good agreement with measurements exhibited by (Kaplan et al, 1979), which includes the important higher harmonics of blade rate, the basic theory used there appears to be a valid representation of the important effects occurring due to propeller blade cavitation.

METHOD OF ANALYSIS - PRESSURE DISTRIBUTION ON SHIP SECTIONS

With knowledge of the free space pressure due to the propeller it is necessary to determine the effect of different ship sections on the actual pressures experienced on the ship hull boundary, i.e. the effect of the ship hull in changing the magnitude of the incident free space pressure. The basic method of analysis used here assumes that a strip theory method is applicable, with the effect of the ship hull section determined by means of a two-dimensional analysis. This procedure is considered to be applicable to the present case since the rate of spatial decay of the pressure field is primarily due to the changing volume of the cavity, which acts as a source whose rate of spatial variation is much smaller than that due to loading variations that has been the primary influence for non-cavitated propellers.

The effect of the ship hull section is evaluated by assuming that the sections can be represented in terms of a multi-parameter conformal mapping that generalizes the Lewis form method (Lewis, 1929) for ship sections. In the present case the incident flow field is that due to the free space pressure field of the propeller, which is evaluated in the plane of the ship section of interest. The method of formulating the boundary value problem appropriate to this type of approach is given below.

Boundary Value Problem

The boundary value problem is established in terms of the pressure as the dependent variable, with the pressure determined by a linear operation on the velocity potential, i.e.

$$p = -\rho_f \left(\frac{\partial}{\partial t} + \overline{U} \frac{\partial}{\partial x} \right) \phi \qquad (3)$$

where ϕ = the velocity potential and the pressure is expressed with respect to atmospheric pressure as a reference. On that basis the boundary value problem for any ship section

is expressed as shown in Figure 2, where the pressure is assumed to be zero on the free surface due to the high frequencies associated with propeller vibratory effects. The requirement that the normal derivative of the pressure is zero on the section boundary follows from the requirement that $\partial\phi/\partial n = 0$ on that boundary; since pressure is defined in terms of linear differentiation operations on the potential, this boundary relationship then follows.

The problem can be simplified further by decomposing the pressure field into a sum of contributions due to the incident flow field p_p due to the propeller free space pressure, p_i due to the image with respect to the free surface, and the additonal pressure p' representing the effects of the ship section

$$p = p_p + p_i + p' \tag{4}$$

The image pressure is selected so that $p_p + p_i = 0$ on the free surface. This is easily accomplished using the representation in Eqns. (1) and (2) (Kaplan et al, 1979) with a simple change in the definition of the distance R for the image terms. The resulting boundary value problem on the free surface and on the ship section boundary is given in Figure 2 in terms of values of the pressure p', i.e.

$$p' = 0 \quad , \quad \text{on free surface} \tag{5}$$

and

$$\frac{\partial p'}{\partial n} = -\left(\frac{\partial p_p}{\partial n} + \frac{\partial p_i}{\partial n}\right), \text{ on the section boundary} \tag{6}$$

The normal derivative of the propeller free space pressure and its image are known functions determined from the properties of the pressure field due to the cavitating propeller, which can be determined from the work of (Kaplan et al, 1979).

This boundary value problem can be put into a simpler form by means of conformal transformations from a ship section

to a unit radius semicircle and from there to a flat plate. In this manner the various boundary values of the pressure and its derivatives are also transformed in such a way that the problem complexity is reduced and the boundary is simplified.

Introducing the complex potential W, whose real part is taken as the pressure, the complex derivative of W in the physical body plane defined by $Z = y + iz$ is given by

$$\frac{dW}{dZ} = \frac{\partial p}{\partial y} - i\,\frac{\partial p}{\partial z} \tag{7}$$

The flow in the body plane is then transformed to the circle plane (ζ-plane) by means of a conformal mapping defined by

$$Z = a_1\left[\zeta + \sum_{n=1}^{\infty} a_{n+1}\,\zeta^{(-2n+1)}\right] \tag{8}$$

The mapping function from the body plane to the circle plane defined by Eqn. (8) requires a_{n+1} to be found in order to relate the coordinates in the body plane to points along the semicircle. The coefficient a_1 is selected as a normalizing factor so that the transformation goes from the body to a semicircle of unit radius.

The complex pressure gradient determined from the complex potential W is then transformed into the circle plane by means of the operation

$$\frac{dW}{d\zeta} = \frac{dW}{dZ}\,\frac{dZ}{d\zeta} \tag{9}$$

With $\zeta = \xi + i_\eta = e^{-i\phi}$ on the unit circle, Eqn. (9) then becomes

$$\frac{dW}{d\zeta} = \frac{\partial p}{\partial \xi} - i\,\frac{\partial p}{\partial \eta} = a_1\left(\frac{\partial p}{\partial y} - i\,\frac{\partial p}{\partial z}\right)\left[1 - \sum_{n=1}^{\infty}(2n-1)\,a_{n+1}\,e^{i2n\phi}\right] \tag{10}$$

which leads to

$$\frac{\partial p}{\partial \xi} = a_1\frac{\partial p}{\partial y}\left[1 - \sum_{n=1}^{\infty}(2n-1)\,a_{n+1}\cos 2n\phi\right] - a_1\,\frac{\partial p}{\partial z}\sum_{n=1}^{\infty}(2n-1)\,a_{n+1}\sin 2n\phi \tag{11}$$

and

$$\frac{\partial p}{\partial \eta} = a_1 \frac{\partial p}{\partial z} \left[1 - \sum_{n=1}^{\infty} (2n-1) a_{n+1} \cos 2n\theta \right] + a_1 \frac{\partial p}{\partial y} \sum_{n=1}^{\infty} (2n-1) a_{n+1} \sin 2n\theta \tag{12}$$

As shown in Figure 3, the mapping then proceeds from the unit semicircle to a flat plate (ω-plane) by means of the transformation

$$\omega = \frac{1}{2}\left(\zeta + \frac{1}{\zeta}\right) \tag{13}$$

where $\omega = \alpha + i\beta$. The pressure gradient realtions are then

$$\frac{dW}{d\omega} = \frac{\partial p}{\partial \alpha} - i\frac{\partial p}{\partial \beta} = \frac{dW}{d\zeta}\frac{d\zeta}{d\omega} \tag{14}$$

where

$$\frac{d\zeta}{d\omega} = 1 \pm \frac{\omega}{\sqrt{\omega^2 - 1}} \tag{15}$$

Since in conformal mapping procedures the normal to the surface is preserved, the pressure gradient $\partial p/\partial \beta$ normal to the flat plate corresponds to the transformed value of the normal derivative of the pressure on the original body section. For the lower surface of the flat plate, which corresponds to the body section boundary, this leads to

$$\frac{\partial p}{\partial \beta} = \frac{\partial p}{\partial \eta} - \frac{\partial p}{\partial \xi}\frac{\alpha}{\sqrt{1-\alpha^2}} \tag{16}$$

The boundary value problem is then shown in Figure 3 as a mixed boundary value problem for the pressure p' along the entire real axis of the ω-plane. All that is needed for establishing the values of the normal derivative along the plate boundary are the values of the a_n quantities in the transformation to the circle plane give by Eqn. (8). Those values are found by a method based upon a least squares-sequential iterative procedure (von Kerczek and Tuck, 1969) for which a computer program was established. The program considered 7 values of the a_{n+1} coefficients (plus the value of a_1) for proper representation of ship sections of practical interest.

INTEGRAL EQUATION - FORMULATION AND SOLUTION

The boundary value problem on the flat plate plane (ω-plane) can be solved by establishing an integral equation by the use of Green's theorem. The Green's function is selected as

$$G(u,v;\alpha,\beta) = \ell n \sqrt{(u-\alpha)^2 + (v-\beta)^2} - \ell n \sqrt{(u-\alpha)^2 + (v+\beta)^2} \tag{17}$$

for which

$$G(u,0;\alpha,\beta) = 0 \tag{18}$$

$$G_v(u,0;\alpha,\beta) = \frac{-2\beta}{(u-\alpha)^2 + \beta^2} \tag{19}$$

Applying Green's theorem to a contour along the real axis with a large circular arc in the lower half-plane and small arcs about the points ± 1, and on the limit as to the small arcs$\to 0$ and the radius of the large circle$\to\infty$, this leads to

$$\begin{aligned} p'(\alpha,\beta) &= \frac{1}{2\pi}\int_{\substack{\text{real}\\ \text{axis}}} (Gp'_v - p'G_v)\,du \\ &= \frac{1}{2\pi}\int_{-1}^{1} p'(u,0)\ \frac{\partial}{\partial\beta}\ \ell n\left[(u-\alpha)^2 + \beta^2\right]du \end{aligned} \tag{20}$$

which is the Poisson formula for the half plane.

Since p'_β is known on the plate, differentiate with respect to β leading to

$$\begin{aligned} p'_\beta(\alpha,\beta) &= \frac{1}{2\pi}\int_{-1}^{1} p'(u,0)\ \frac{\partial^2}{\partial\beta^2}\ \ell n\left[(u-\alpha)^2 + \beta^2\right]du \\ &= -\frac{1}{2\pi}\ \frac{\partial^2}{\partial\alpha^2}\int_{-1}^{1} p'(u)\ \ell n\left[(u-\alpha)^2 + \beta^2\right]du \end{aligned} \tag{21}$$

by means of the Laplace equation. Integrating both sides with respect to α (from -1 up to α), and letting $\beta\to 0$ while taking ap-

propriate limits and values, leads to

$$c + \int_{-1}^{\alpha} f(s)ds = \frac{1}{\pi} \int_{-1}^{1} \frac{p'(u)}{u-\alpha} du \tag{22}$$

where $f(\alpha)$ is the known value of p_3' along the flat plate. As discussed previously that value is found at any ship section from knowledge of the propeller and free surface image pressure gradients and the mapping coefficients (multiparameter transformation from Z to ζ-planes), with the basic expressions shown in Eqns. (11), (12) and (16).

The singular integral equation in Eqn. (22) is essentially the same as that in (Kaplan and Sargent, 1972) and the solution is also similar. With the requirement of the solution being bounded at both ends (± 1), it is given by

$$p'(\alpha) = -\frac{1}{\pi} \sqrt{1-\alpha^2} \int_{-1}^{1} \frac{\int_{-1}^{u} f(s)ds \, du}{\sqrt{1-u^2} \quad (u-\alpha)} \tag{23}$$

as indicated by the methods in (Muskhelishvili, 1963).

The solution in Eqn. (23) is evaluated by defining new variables, i.e. $u = \cos\theta$, $\alpha = \cos\theta_0$ and it is assumed that the integral $\int_{-1}^{u} f(s)ds$ can be expanded into a Fourier series form in terms of cosines, viz.

$$\int_{-1}^{u} f(s)ds = \sum_{n=1}^{\infty} A_n \cos n\theta \tag{24}$$

Substituting the new variables and the Fourier expression of Eqn. (24) leads to

$$p'(\alpha) = -\sum_{n=1}^{\infty} A_n \sin n\,\theta_0 \tag{25}$$

where $\theta_0 = \cos^{-1}\alpha$, by use of the Glauert integrals of airfoil theory (Glauert, 1937).

The pressure distribution along the ship section boundary of interest is found by adding the contribution from Eqn. (25)

together with the free space pressure of the cavitating propeller as well as its free surface image. The computational procedure considers the separate sine and cosine harmonic terms at blade rate and higher harmonics from each constituent term, adding all contributions to each oscillatory function and then determining the resulting amplitude and phase of the final total pressure signal on the boundary.

The pressure distribution is determined at points along the section boundary that correspond to points that are equally spaced in the unit circle in the ζ-plane, i.e. equally spaced angles. This procedure assists in the determination of the Fourier cosine coefficients in the expansion of Eqn. (24). The location of the points on the section in the Z-plane is readily determined by use of Eqn. (8), which establishes the locations at which the pressures and pressure gradients from the cavitating propeller and its free surface image are to be calculated.

The total lateral and vertical force on each section are determined by integrating the pressure along the boundary, with appropriate account of directions, separate sine and cosine components for each harmonic of blade rate, etc. With knowledge of the sectional forces obtained in this manner the total forces are obtained by integrating the section forces along the length of the hull, which is the conventional procedure employed in strip theory analyses. Devoting the local sectional forces as $F_z'(x)$ and $F_y'(x)$ for the vertical and lateral forces, the total vertical and lateral forces on the ship due to the pressures arising from a cavitating propeller are represented by

$$F_z = \int F_z'(x)\,dx \; , \; F_y = \int F_y'(x)\,dx \qquad (26)$$

The integrations in Eqn. (26) extend over a length region for which appreciable pressures and forces exist on the ship, which is determined either computationally, or by establishing a cut-off level, or arbitrarily to some location such as up

to midships at which the pressures and forces will generally be negligible. When considering the force information to determine forced vibratory response of a ship, by use of a modal method of analysis as an example (McGoldrick, 1960), the total force integral is weighted by a modal weighting function, viz. the normal mode shape $X_i(x)$ for the i^{th} normal mode. The generalized modal force is then represented by

$$F_{z_i} = \int F_z'(x) X_i(x) dx \tag{27}$$

as a typical example, with appropriate consideration of the particular blade rate harmonic force values being used in such expressions. The use of a strip theory approach, with modal weighting from response analysis, has been used in various ship dynamic problems such as slamming response analysis (Kaplan and Sargent, 1972) and has proven to be a useful method for response predictions.

A listing of the computer program that solves the integral equation in the manner described above for use in determining the pressure distribution along the ship section is given in the Appendix. This computer program includes within its various procedures the calculation of the free space pressure due to a cavitating propeller; the pressure contribution due to the image; the determination of the various required pressure gradients; the conformal mapping and other coordinate transformations; etc. The procedures for determining the total forces acting on the ship, as well as the generalized modal forces, are also included in this program.

APPLICATION AND DISCUSSION OF RESULTS

In order to illustrate the nature of the results obtained from the preceding analysis, some representative calculations are carried out. The basic computational procedures that are necessary for the case of a cavitating propeller for a particular ship are described in block diagram form in Figs. 4 and 5. The procedure in Fig. 4 represents the various steps associated with the calculation of the pressure field arising from a particular propeller in a specified wake field, as described by (Kaplan et al, 1979). The diagram in Fig. 5 essentially describes the procedures developed in the present report.

The particular case illustrated here considers the auxiliary naval vessel designated as AO-177, which is a single screw tanker vessel. The propeller has 7 blades, with 45 deg. skew angle, with a 21 ft. diameter. This ship has been studied in a number of special investigations, with consideration of the occurrence of cavitation on the propeller blades due to the particular ship wake, e.g. (Bentson and Kaplan,1981a,1981b). Model tests have been carried out by David Taylor Naval Ship Research and Development Center for the basic ship to measure its wake field, as well as for the case where special flow-modifying fins were installed on the ship, with that data provided as input information that is used for the present calculations.

For the present purpose the particular wake, propeller design, etc. of the AO-177 is used only as a means of illustrating the nature of results for representative ship sections when using the present analysis. The various representative ship sections used for illustrating the present results are not necessarily those of the AO-177, although the flow field from which the propeller cavitation disturbing flows arise does correspond to that particular ship. The first case illustrated is that of a flat plate with a width of 60 ft. which is located in the free surface, where that section is assumed to be located at a distance of

5 ft. aft of the propeller plane (i.e. x=5 ft.). The wake field is that corresponding to the AO-177 fitted with the fins.

Calculations were made to determine the free space pressure along this flat plate section, as well as using the methods of the present analysis to determine the actual pressure inclusive of all other flows that would satisfy the boundary conditions of the present problem. An important feature of the results is not necessarily the pressures per se, but the ratio of the pressure along the plate to that of the free space pressure at each point along the plate. The results of this computation are shown in Fig. 6 illustrating the ratio of the pressure on the plate to the local free space pressure. Two curves are shown here in order to illustrate the accuracy of the results as a function of the number of points along the plate that are taken as input information for the integral equations. The differences due to the different number of points are more predominant in the region of the larger pressures, although the extent of such differences is not very significant. It can be seen by examination of Fig. 6 that the pressure on the plate increases to a value of the order of 2.6 times the local free space pressure, with the values of the pressure falling off to zero at the ends of the plate as expected. The average pressure for this distribution was found by means of integration, and was found to be 1.94 as is also illustrated in Fig. 6, with that value being close to the usual assumed value of the factor of 2 that is applied to free space pressures when determining pressure effects along a boundary.

While the results in Fig. 6 are informative, that only illustrates information appropriate to a particular special case. Other results are described below which have different numerical values and provide a different interpretation for the effect of the interaction of a representative ship section and the incident flow from a cavitating propeller.

Another case considers a flat plate section of 21.6 ft. width which is located in the free surface at the same position (i.e. x=5 ft.) in the wake due to the AO-177 with fins. The ratio of the pressure to the local free space pressure due to the propeller along this plate is shown in Fig. 7. It can be seen that this ratio has a maximum value of just under 1.4, with that maximum occurring near the plate center but slightly to port. This result illustrates the nature of the influence of the size of the plate relative to the disturbing flow field and/or the propeller.

Another application of the analysis considers an actual ship section taken from the AO-177, with that section being the profile corresponding to Station 19.5 on that vessel as illustrated in Figure 8. This section is essentially a shallow V-wedge shape, with the total lateral extent equal to 21.6. Assuming that this particular section is located at the position corresponding to x=5 ft. relative to the propeller, and with the wake the same as that of the AO-177 fitted with fins (the same case as for Figs. 6 and 7), the ratio of the pressure to the free space pressure along this section is shown in Fig. 9. In that situation the ratio reaches a maximum value of 2.0, with that maximum occurring somewhat to the starboard of the middle of the section. This result, when contrasted with that in Fig. 7, illustrates the effects of the actual section shape as well as the influence of the proximity of the center of the wedge region relative to the propeller tip.

Another illustration considers the same section corresponding to Station 19.5 of the AO-177, with the propeller operating in the basic wake of that ship without any flow-modifying fins. The section is assumed to be located 6 ft. forward of the propeller plane (x=-6 ft.) and the results for the ratio of the pressure along the plate to that of the local free space pressure due to the propeller are shown in Fig. 10. In that case the maximum value of this particular pressure ratio is 1.4, occurring somewhat to port

of the center of the section.

All of the above results illustrate the effect of the size of the section as well as its shape in regard to determining the magnitude of the pressures along different ship sections. The so-called boundary factor that accounts for the influence of the body section results in an increase in the value of the free space pressure to some factor that ranges both above and below the number 2, with the particular maximum value dependent upon the nature of the lateral size extent of the section, the shape of the section, the nature of the distribution of the free space pressure, etc. In addition the requirement that the pressure goes to zero at the ends of the section at the free surface is also a significant aspect of the present analysis that will affect the magnitude of the pressure distribution acting on various ship sections. All of these features influence the resulting pressure distribution values, indicating the basic complexity of determining the pressures on different ship sections and reducing the significance of the use of simplified factors for prediction of propeller-induced pressures and forces.

EFFECT OF RIGID FREE SURFACE CONDITIONS

In the preceding analysis the mathematical problem was formulated with the boundary condition corresponding to p=0 on the free surface. This particular boundary condition applies to the physical conditions corresponding to high frequencies, which is generally appropriate for the case of propeller-induced unsteady flows. There has been some previous analysis which considered the effects of different boundary conditions on the free surface (Vorus, 1976), where that analysis was applied to noncavitated propellers and was concerned with the total force as well as the local force on a strip section of a semi-infinite flat plate.

Aside from the basic interest in the influence of the free surface boundary condition, the consideration of a rigid wall free surface condition is important because it is representative of the flow conditions associated with model test procedures for ships in specialized water tunnel facilities that simulate full scale operation. In that case the free surface region is covered by rigid plates whose extent laterally can generally be represented by employing the boundary conditions of a rigid wall out to $\pm\infty$. On that basis the boundary condition for the pressure would correspond to $\partial p/\partial n = 0$ for the free surface as well as on the ship section boundary.

This problem can be analyzed by methods similar to that used for the case with a free surface boundary condition corresponding to p=0 by introducing a special image flow that results in satisfying the condition $\partial p/\partial z = 0$ on the free surface. This particular image is essentially the negative of the previous free surface image used for the earlier boundary condition, so that the total pressure can be represented by the expression

$$p = p_p + p_r + p' \tag{28}$$

where p_r = the pressure induced by the rigid wall image ($p_r = -p_i$, as defined previously). The resulting boundary

value problem on the ship section and the free surface is given by

$$\frac{\partial p'}{\partial n} = 0 \text{ , on the free surface} \tag{29}$$

$$\frac{\partial p'}{\partial n} = -\left(\frac{\partial p_p}{\partial n} + \frac{\partial p_r}{\partial n}\right), \text{ on the section boundary} \tag{30}$$

where the required normal derivatives can be found from the cavitating propeller and the appropriate image.

By carrying out the same mapping procedures to the ζ and ω-planes, the resulting boundary value problem in the ω-plane is shown in Fig. 11. This boundary value problem can be solved by the use of Green's theorem, with the Green's function selected as

$$G(u,v;\alpha,\beta) = \ln \sqrt{(u-\alpha)^2+(v-\beta)^2} + \ln \sqrt{(u-\alpha)^2+(v+\beta)^2} \tag{31}$$

for which

$$G(u,0;\alpha,\beta) = 2 \ln \sqrt{(u-\alpha)^2+\beta^2} \tag{32}$$

$$G_v(u,0;\alpha,\beta) = 0 \tag{33}$$

By applying Green's theorem to the same type contour as was done previously, the basic solution for the pressure is given in terms of the values of the derivative p'_β on the plate, which is represented by the function $g(\alpha)$, in the form

$$p'(\alpha) = \frac{1}{\pi}\int_{-1}^{1} g(u) \ln|u-\alpha| du \tag{34}$$

The value of $g(\alpha)$ is determined from the same basic relations as in Eqn. (16) applied to the combined pressure values found from the propeller and the rigid wall image. With the expression for the value of p' on the flat plate given above by Eqn. (34), this value is then transformed back to the appropriate points along the actual ship section boundary in the body plane. To this value is added the pressure values arising from the propeller and the rigid wall image,

resulting in the total pressure distribution as defined by Eqn. (28).

The above procedure describes the method for determining the pressure distribution on the ship section when considering a rigid wall free surface boundary condition rather than the conditions that are appropriate to the real physical case in full scale. Numerical evaluation for parrticular cases (which is not done here) will provide information on the pressure distribution appropriate to both sets of boundary conditions on the free surface, so that comparisons can then be made between the different results that arise from each set of conditions. In that way it is possible to evaluate the influence of the boundary effects applied in laboratory test facilities that do not employ an actual free surface, so that the influence of these boundary effects can be determined relative to what would be present for full scale flow conditions.

CONCLUSION

The method of analysis described herein provides a technique for determining the pressure distribution along different ship sections due to a cavitating propeller, with appropriate account of the effects of the free surface boundary condition and the influence of the body shape. The major results are presented for the case wherein the free surface boundary condition corresponding to zero pressure is imposed, with the resulting pressure distribution illustrating the manner in which the pressure reduces toward zero at the intersection of the section with the free surface. The figures illustrating the results demonstrate the difference between a more precise method of solution and the simplified methods that are usually applied in engineering practice.

As a result of the analysis presented here, a straightforward procedure is then available for determining pressure distributions, local forces at various sections of a ship, and also the total force due to the disturbing flows arising from a cavitating propeller, including a procedure for modal weighting for use in vibratory analysis. The analytical tool described here is recommended for further practical applications to various problems of interest involving propeller-excited vibrations.

The analysis in the case of a rigid wall free surface boundary condition provides an entirely different type of solution that describes the pressure distribution under such a boundary condition. Since that type of boundary condition corresponds to the physical characteristics associated with particular types of model test facilities used for determining propeller vibratory pressures on ship hull sections, the analysis shown herein provides a means of representing the effects due to an imposed propeller pressure field. Comparisons can be made between the results predicted with the rigid wall boundary condition vis-a-vis

those from the zero pressure free surface condition as a means of illustrating the effects of model test facility boundary influence on measured pressures on ship hulls obtained from tests in such facilities.

It is recommended that extended calculations be carried out by these different approaches in order to provide guidance that will assist in interpreting the relation of model test values to the actual full scale pressures on ships with cavitating propellers. In view of the present use of such test facilities for predicting propeller-induced vibratory pressures and their associated effects, as well as possible new facilities built with the same basic testing concept, such an investigation has practical importance.

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APPENDIX

COMPUTER PROGRAM LISTING

```
      PROGRAM CAV(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)                 CAV        2
C     PROGRAM CAV                                                        CAV        3
C                                                                        CAV        4
C     PROGRAM CAV CALCULATES RADIATED PRESSURE AND CHANGES IN STEADY     CAV        5
C     AND UNSTEADY FORCE AND MOMENT COEFFICIENTS DUE TO PROPELLER        CAV        6
C     CAVITATION - METHOD IS BASED ON QUASI-STEADY APPLICATION OF THE    CAV        7
C     CAVITATION SOLUTIONS OF GEURST FOR AN EQUIVALENT PARABOLIC ARC     CAV        8
C     FOIL WITH THE SAME SECTIONAL (SPANWISE) LOADING                    CAV        9
C                                                                        CAV       10
C     PROGRAM WRITTEN BY HYDROMECHANICS INC.                             FINAL4     1
C                                                                        CAV       12
      COMMON/CONST/PI,RHOF,U,OMEGA,DEPTH,PV,G,RAD                        CAV       13
      COMMON/EXEC/TOL,       NPTS,DTHETA,ISOL,NITMAX        ,NOMAX       CAV       14
      COMMON/FORCES/XLO,XLREAL(22),XLIMAG(22)                            CAV       15
      COMMON/GEOM/        NRAD,RO,RIND,DRND,PSKEW(8),PCHORD(8)           CAV       16
      COMMON/POINTS/NPLOC,XPT(100),RHOPT(100),PHIPT(100)                 NEWFIX     2
      COMMON/ZERO/ YTOT(6),ZTOT(6)                                       FINAL1     1
      COMMON /SOLUTN/DLIFT(8,181),VEL(8)                                 ADDGRAD    1
      COMMON/UNITS/NIN,NOUT                   ,DATE(5),TITLE(15)         CAV       19
      COMMON/GRADS/DXLDTH(8,181),DSDTH(8,181),D2SDTH(8,181),NREG(8),     ADDGRAD    2
     1P(181),DPDY(181),DPDZ(181),NX1(8,30),NX2(8,30),XL(8,181)           ADDGRAD    3
      DIMENSION COEFM(181),AREA(181),                                    ADDGRAD    4
     1            ALPHAD(181),SIGMAP(181),XLSTVN(181)                    CAV       21
      DIMENSION DCMDTH(181)                                              ADDGRAD    5
      DIMENSION DUMMY(1)                                                 CAV       23
      DIMENSION IREGNS(30)                                               ADDGRAD    6
      DIMENSION WORK1(181),WORK2(181),WORK3(181)                         ADDGRAD    7
      DIMENSION N1(30),N2(30),XL1(181)                                   ADDGRAD    8
      DIMENSION TYPES(9)                                                 CAV       25
      DATA TYPES/4HPART,4HIAL ,4H    ,4HTRAN,4HSITI,4HONAL,4HFULL,       CAV       26
     1 4H    ,4H    /                                                    CAV       27
C                                                                        CAV       28
C     READ INPUT                                                         CAV       29
C                                                                        CAV       30
      CALL INPUT                                                         CAV       31
      TWOPI=2.*PI                                                        CAV       32
C                                                                        CAV       33
C     ZERO SOLUTION ARRAYS                                               CAV       34
C                                                                        CAV       35
      DO  89 J=1,NPTS                                                    CAV       36
      DO 89 K=1,8                                                        CAV       37
      DLIFT(K,J)=0.0                                                     CAV       38
   89 CONTINUE                                                           CAV       40
C                                                                        CAV       41
C     START LOOP OVER RADIAL STRIPS                                      CAV       42
C                                                                        CAV       43
      DO 1000 K=1,NRAD                                                   CAV       44
      DO 987 J=1,30                                                      CAV       45
      N1(J)=0.0                                                          ADDGRAD    9
      N2(J)=0.0                                                          ADDGRAD   10
  987 CONTINUE                                                           CAV       48
C                                                                        CAV       49
C     GET GEOMETRIC PROPERTIES FOR GIVEN RADIAL STRIP                    CAV       50
C                                                                        CAV       51
      RNC=RIND+(K-1)*DRNC                                                CAV       52
      R=RNC*RO                                                           CAV       53
      CHORD=PCHORD(K)                                                    CAV       56
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      SKEW=PSKEW(K)                                                     CAV      57
      VSQD=U*U+(R   *OMEGA)**2                                          CAV      58
      V=SQRT(VSQD)                                                      CAV      59
      VEL(K)=V                                                          CAV      60
      FACLFT=.5*RHOF*CHORD*VSQD                                         CAV      61
      DENOM=FACLFT*TWOPI                                                CAV      62
      FACMAS=FACLFT*OMEGA*CHORD/V                                       CAV      63
C                                                                       CAV      64
C     GET NON-CAVITATING LOADING FOR GIVEN RADIAL STRIP                 CAV      65
C                                                                       CAV      66
      CALL INLCS(  NOMAX)                                               CAV      67
C                                                                       CAV      68
C     CALCULATE EFFECTIVE CAMBER FROM THE STEADY LIFT                   CAV      69
C                                                                       CAV      70
      CAMBER=-XLO/DENOM                                                 CAV      71
C                                                                       CAV      72
C     SUMMARIZE INPUT FOR CURRENT RADIAL STRIP                          CAV      73
C                                                                       CAV      74
      CALL HEADIN                                                       CAV      75
      WRITE(NOUT,200)RND,V,CAMBER                                       CAV      76
      WRITE(NOUT,2000)                                                  CAV      77
      J=0                                                               CAV      78
      WRITE(NOUT,201)J,XLO                                              CAV      79
      DO 4455 J=1,NOMAX                                                 CAV      80
      WRITE(NOUT,201)J,XLREAL(J),XLIMAG(J)                              CAV      81
 4455 CONTINUE                                                          CAV      82
      ITOLD=0                                                           CAV      83
      NREGNS=0                                                          CAV      84
C                                                                       CAV      85
C     START LOOP OVER ANGULAR POSITIONS                                 CAV      86
C                                                                       CAV      87
      DO 3 I=1,NPTS                                                     CAV      88
      DXLDTH(K,I)=0.0                                                   ADDGRAD  11
      DSDTH(K,I)=0.0                                                    ADDGRAD  12
      D2SDTH(K,I)=0.0                                                   ADDGRAD  13
      DCMDTH(I)=0.0                                                     ADDGRAD  14
C                                                                       CAV      93
C     CALCULATE EFFECTIVE (QUASI-STEADY) ANGLE OF ATTACK FROM UNSTEADY  CAV      94
C     LIFT                                                              CAV      95
C                                                                       CAV      96
      ALPHA=0.0                                                         CAV      97
      THETA=(I-1)*DTHETA                                                CAV      98
      XLIFT=-XLO                                                        CAV      99
      DO 2 J=1,NOMAX                                                    CAV     100
      Q=J                                                               CAV     101
      COSQTH=COS(Q*THETA)                                               CAV     102
      SINQTH=SIN(Q*THETA)                                               CAV     103
      ARG=(Q*OMEGA*CHORD)/(4.*V)                                        CAV     104
      DALPHA=-(COSQTH*(XLREAL(J)+ARG*XLIMAG(J))+SINQTH*(XLIMAG(J)       CAV     105
     1 -ARG*XLREAL(J)))/((1.+ARG*ARG)*DENOM)                            CAV     106
      XLIFT=XLIFT-(COSQTH*XLREAL(J)+SINQTH*XLIMAG(J))                   CAV     107
      ALPHA=ALPHA+DALPHA                                                CAV     108
    2 CONTINUE                                                          CAV     109
      XLSTVN(I)=XLIFT                                                   CAV     110
C                                                                       CAV     111
C     CALCULATE NON-CAVITATING LIFT AND MOMENT COEFFICIENTS             CAV     112
C                                                                       CAV     113
```

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      CLNOCV=TWOPI*(ALPHA+CAMBER)                                       CAV       114
      CMNOCV=-.5*PI*ALPHA                                               CAV       115
      IF(ALPHA.LE. 0.0) GO TO 78                                        CAV       116
      PA=2116.+RHOF*G*(DEPTH-R    *COS(THETA+SKEW))                     CAV       117
      SIGMA=2.*(PA-PV)/(RHOF*VSQD)                                      CAV       118
C                                                                       CAV       119
C     FIND APPROPRIATE CAVITATION SOLUTION (PARTIAL, TRANSITIONAL,      CAV       120
C     FULL)                                                             CAV       121
C                                                                       CAV       122
      ALMAX=.25*SIGMA-.30901*CAMBER                                     CAV       123
      ALMIN=.085786    *SIGMA-.20711    *CAMBER                         CAV       124
      IF(ALPHA.LT. ALMIN )GO TO 5                                       CAV       125
      IF(ALPHA.GT. ALMAX ) GO TO 6                                      CAV       126
C                                                                       CAV       127
C     TRANSITIONAL CAVITY SOLUTION                                      CAV       128
C                                                                       CAV       129
      CALL TRANS(ALPHA,SIGMA,CAMBER,CAVLEN,CL,CMASS,S,ALMIN,ALMAX)      CAV       130
      ITYPE=2                                                           CAV       131
      GO TO 7                                                           CAV       132
    5 CONTINUE                                                          CAV       133
C                                                                       CAV       134
C     PARTIAL CAVITY SOLUTION                                           CAV       135
C                                                                       CAV       136
      CALL PARCAV(ALPHA,SIGMA,CAMBER,CAVLEN,CL,CMASS,S,0)               CAV       137
      ITYPE=1                                                           CAV       138
      IF(CAVLEN.EQ. 0.0) GO TO 78                                       CAV       139
C                                                                       CAV       140
C     GET CAVITY AREA FROM CUBIC CURVE FIT (TRANSITIONAL OR             CAV       141
C     PARTIAL SOLUTIONS ONLY)                                           CAV       142
C                                                                       CAV       143
    7 CALL CUBIC(ALPHA,SIGMA,CAMBER,ALMAX,S)                            CAV       144
      GO TO 77                                                          CAV       145
    6 CONTINUE                                                          CAV       146
C                                                                       CAV       147
C     FULL CAVITY SOLUTION                                              CAV       148
C                                                                       CAV       149
      CALL FULCAV(ALPHA,SIGMA,CAMBER,CAVLEN,CL,CMASS,S,0)               CAV       150
      ITYPE=3                                                           CAV       151
      GO TO 77                                                          CAV       152
C                                                                       CAV       153
C     NO CAVITATION                                                     CAV       154
C                                                                       CAV       155
   78 CAVLEN=0.0                                                        CAV       156
      CL=CLNOCV                                                         CAV       157
      CMASS=CMNOCV                                                      CAV       158
      S=0.0                                                             CAV       159
      ITYPE=0                                                           CAV       160
   77 CONTINUE                                                          CAV       161
C                                                                       CAV       162
C     COMPUTE AND STORE DIMENSIONAL CAVITY SOLUTION                     CAV       163
C                                                                       CAV       164
      ALPHAC(I)=ALPHA*RAD                                               CAV       165
      SIGMAP(I)=SIGMA                                                   CAV       166
      XL(K,I)=CAVLEN*CHORD                                              ADDGRAD    15
C                                                                       CAV       168
C     DIFFERENCE BETWEEN CAVITATING AND NON-CAVITATING LIFT IS USED     CAV       169
C                                                                       CAV       170
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      C     USE CAVITY + LIFT SOLUTIONS                                         CAV        171
            CLNOCV=0.0                                                          CAV        172
            CMNCCV=0.0                                                          CAV        173
            DLIFT(K,I)=           (CL-CLNOCV)*FACLFT                            CAV        174
            CCEFM(I)= CMASS-CMNOCV                                              CAV        175
            AREA(I)=S  *CHORD*CHORD                                             CAV        176
      C                                                                         CAV        177
      C     STORE TYPE OF SOLUTION AND CALCULATE END POINT INDICES              CAV        178
      C                                                                         CAV        179
            IF(ITYPE.EQ.ITOLD) GO TO 53                                         CAV        180
            IF(ITYPE.NE.0) GO TO 52                                             CAV        181
            N2(NREGNS)=I-1                                                      CAV        182
            GO TO 53                                                            CAV        183
   52       CONTINUE                                                            CAV        184
            NREGNS=NREGNS+1                                                     CAV        185
            N1(NREGNS)=I                                                        CAV        186
            IREGNS(NREGNS)=ITYPE                                                CAV        187
            IF(NREGNS.EQ.1) GO TO 53                                            CAV        188
            IF(ITOLD.EQ.0) GO TO 53                                             CAV        189
            N2(NREGNS-1)=I-1                                                    CAV        190
   53       CONTINUE                                                            CAV        191
            ITOLD=ITYPE                                                         CAV        192
    3       CONTINUE                                                            CAV        193
            IF(XL(K,NPTS) .NE. 0.0) N2(NREGNS)=NPTS                             ADDGRAD     16
      C                                                                         CAV        195
      C     PRINT CAVITATION SUMMARY (REGIONS AND TYPE)                         CAV        196
      C                                                                         CAV        197
            WRITE(NOUT,100)                                                     CAV        198
            IF(NREGNS.EQ.0) GO TO 1010                                          CAV        199
            NFIRST=N1(1)                                                        CAV        200
            NCOUNT=0                                                            ADDGRAD     17
            DO 22 J=1,NREGNS                                                    CAV        201
            T1=(N1(J)-1)*DTHETA*RAD                                             CAV        202
           1 +SKEW*RAD                                                          PRINTANG     1
            T1=AMOD(T1,360.)                                                    PRINTANG     2
            T2=(N2(J)-1)*DTHETA*RAD                                             CAV        203
           1 +SKEW*RAD                                                          PRINTANG     3
            T2=AMOD(T2,360.)                                                    PRINTANG     4
            IND1=3*(IREGNS(J)-1)+1                                              CAV        204
            IND2=IND1+2                                                         CAV        205
            WRITE(NOUT,150)T1,T2,(TYPES(L),L=IND1,IND2)                         CAV        206
            IF(N1(J+1).EQ.(N2(J)+1)) GO TO 22                                   CAV        207
            NLAST=N2(J)                                                         CAV        208
      C                                                                         CAV        209
      C     ELIMINATE REGIONS WHICH EXIST FOR LESS THAN 4 DEGS OF BLADE         CAV        210
      C     MOTION FROM CALCULATION OF DERIVATIVES                              CAV        211
      C                                                                         CAV        212
            IF((NLAST-NFIRST).LT.2) GO TO 27                                    CAV        213
      C                                                                         CAV        214
      C     CALCULATE TIME DERIVATIVES FOR PRESSURE AND LIFT CALCULATIONS       CAV        215
      C                                                                         CAV        216
            NCOUNT=NCOUNT+1                                                     ADDGRAD     18
            CALL DERIV(NFIRST,NLAST,DTHETA,CCEFM,DCMDTH,DUMMY,C,1,0)            CAV        217
            DO 25 M=NFIRST,NLAST                                                ADDGRAD     19
         25 XL1(M)=XL(K,M)                                                      ADDGRAD     20
            CALL DERIV(NFIRST,NLAST,DTHETA,XL1,WORK1,DUMMY,0,1,0)               ADDGRAD     21
            CALL DERIV(NFIRST,NLAST,DTHETA,AREA,WORK2,WORK3,0,C,C)              ADDGRAD     22
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      C                                                               ADDGRAD    23
      C      RELOAD DERIVATIVES INTO TWO DIMENSIONAL ARRAYS           ADDGRAD    24
      C                                                               ADDGRAD    25
             NX1(K,NCOUNT)=NFIRST                                     ADDGRAD    26
             NX2(K,NCOUNT)=NLAST                                      ADDGRAD    27
             DO 26 M=NFIRST,NLAST                                     ADDGRAD    28
             DXLDTH(K,M)=WORK1(M)                                     ADDGRAD    29
             DSDTH(K,M)=WORK2(M)                                      ADDGRAD    30
          26 D2SDTH(K,M)=WORK3(M)                                     ADDGRAD    31
      27     NFIRST=N1(J+1)                                           CAV       221
      22     CONTINUE                                                 CAV       222
             IF(N1(1).NE.1) GO TO 24                                  CAV       223
      C                                                               CAV       224
      C      ENSURE DERIVATIVES MATCH AT 0 DEG AND 360 DEG            CAV       225
      C                                                               CAV       226
             DCMDTH(1)=.5*(-COEFM(NPTS-1)+COEFM(2))/DTHETA            ADDGRAD    32
             DCMDTH(NPTS)=DCMDTH(1)                                   ADDGRAD    33
             DSDTH(K,1)=.5*(-AREA(NPTS-1)+AREA(2))/DTHETA             ADDGRAD    35
             DSDTH(K,NPTS)=DSDTH(K,1)                                 ADDGRAD    36
             D2SDTH(K,1)=(AREA(NPTS-1)-2.*AREA(1)+AREA(2))/(DTHETA*DTHETA)  ADDGRAD    37
             D2SDTH(K,NPTS)=D2SDTH(K,1)                               ADDGRAD    38
             DXLDTH(K,1)=.5*(-XL(K,NPTS-1)+XL(K,2))/DTHETA            ADDGRAD    39
             DXLDTH(K,NPTS)=DXLDTH(K,1)                               ADDGRAD    40
      24     CONTINUE                                                 CAV       236
             IF(ISOL.NE.0) WRITE(NOUT,400)                            CAV       237
             DO 377J=1,NREGNS                                         CAV       238
             NFIRST=N1(J)                                             CAV       239
             NLAST=N2(J)                                              CAV       240
             DO 37 I=NFIRST,NLAST                                     CAV       241
      C                                                               CAV       242
      C      CALCULATE ADDED MASS EFFECTS ON LIFT                     CAV       243
      C                                                               CAV       244
             DLIFT(K,I)=DLIFT(K,I)+DCMDTH(I)*FACMAS                   CAV       245
      C                                                               CAV       246
      C      WRITE COMPLETE CAVITATION TIME HISTORY IF REQUESTED      CAV       247
      C                                                               CAV       248
             IF(ISOL.EQ.0) GO TO 37                                   CAV       249
             THETAD=((I-1)*DTHETA+SKEW)*RAD                           PRINTANG    5
             THETAD=AMOD(THETAD,360.)                                 PRINTANG    6
             CAVLEN=XL(K,I)/CHORD                                     ADDGRAD    41
             CLRAT=CLIFT(K,I)/XLSTVN(I)                               ADDLIFT     1
             WRITE(NOUT,403)THETAD,ALPHAU(I),SIGPAP(I),CAVLEN,AREA(I),CLRAT  CAV       253
      37     CONTINUE                                                 CAV       254
             IF(NLAST.NE.N1(J+1)-1) WRITE(NOUT,404)                   CAV       255
      377    CONTINUE                                                 CAV       256
             NREG(K)=NCOUNT                                           ADDGRAD    42
             GO TO 1000                                               CAV       282
      1010   WRITE(NOUT,333)                                          CAV       283
      1000   CONTINUE                                                 CAV       284
      C                                                               CAV       290
             DO 19 LL=1,6                                             FINAL1      2
             YTOT(LL)=0.0                                             FINAL1      3
          19 ZTOT(LL)=0.0                                             FINAL1      4
          93 CALL INPUT2                                              NEWFIX      3
             DO 21 KK=1,6                                             FINAL1      5
             YTOT(KK)=0.0                                             FINAL1      6
          21 ZTOT(KK)=0.0                                             FINAL1      7
```

```
      C                                                                         CAV        292
            CALL PRESS                                                          CAV        293
            CONTINUE                                                            MERGOPN      1
            CALL TRANSF                                                         MERGOPN      2
            GO TO 53                                                            NEWFIX       4
        333 FORMAT(/43X,6H(NONE))                                               CAV        295
        200 FORMAT(     10X,23HRADIAL LOCATION (R/RO)= ,F5.3,5X,22HINFLOW VELO  CAV        296
           1CITY (FPS)=  ,F8.2,5X,23HEFFECTIVE BLADE CAMBER= ,F7.4//)           CAV        297
        100 FORMAT(//38X,18HCAVITATION SUMMARY  /37X,20(1H*)//                  CAV        298
           1 19X,55HINITAL BLADE POSITION   FINAL BLADE POSITION      TYPE /   CAV        299
           2 19X,55H       (DEG)                 (DEG)                     /)  CAV        300
        150 FORMAT(F31.0,F23.0,16X,3A4)                                         CAV        301
        400 FORMAT(//72X,105HBLADE POSITION  ANGLE OF ATTACK  CAVITATION NUMBER CAV        302
           1  CAVITY LENGTH/CHORD  CAVITY AREA     CL/CL(NO CAVITY)  /          CAV        303
           2    7X,5H(DEG),11X,5H(DEG),49X,7H(FT**2)  /)                        CAV        304
        403 FORMAT(F12.0,F16.3,F18.4,F19.4,F18.4,F16.4)                         CAV        305
       2000 FORMAT(          23X,47HHARMONIC DISTRIBUTION OF INPUT SPANWISE LOAD CAV        306
           XING  /22X,49(1H*)                                                   CAV        307
           1      //26X,41HHARMONIC      REAL PART       IMAGINARY PART        CAV        308
           2      /26X,41H              (LBS/FT)         (LBS/FT)        /)    CAV        309
        201 FORMAT(27X,I2,F18.2,F16.2)                                          CAV        310
        404 FORMAT(/)                                                           CAV        311
            END                                                                 CAV        312
```

```
      SUBROUTINE CUBIC(ALPHA,SIGMA,CAMBER,ALMAX,S)                      CUBIC   2
C                                                                       CUBIC   3
C     SUBROUTINE CUBIC CALCULATES THE CAVITY AREA (NON-DIM) IN THE      CUBIC   4
C     TRANSITION AND PARTIAL CAVITATION REGION BY A CUBIC CURVE FIT     CUBIC   5
C     WHICH MATCHES THE VALUE AND DERIVATIVE WITH RESPECT TO ALPHA      CUBIC   6
C     AT THE END POINTS WITH THE FULL AND NON-CAVITATING SOLUTIONS      CUBIC   7
C                                                                       CUBIC   8
      DATA DRATIO/.01/                                                  CUBIC   9
C                                                                       CUBIC  10
C     CALCULATE INDEPENDENT VARIABLE                                    CUBIC  11
C                                                                       CUBIC  12
      RATIO=ALPHA/ALMAX                                                 CUBIC  13
C                                                                       CUBIC  14
C     GET VALUE OF AREA AT FULL CAVITY END POINT                        CUBIC  15
C                                                                       CUBIC  16
      CALL FULCAV(ALMAX,SIGMA,CAMBER,XL,CL,CPASS,S1,1)                  CUBIC  17
      VALUE=  S1                                                        CUBIC  18
C                                                                       CUBIC  19
C     INCREMENT ALPHA AT END POINT TO GET SLOPE                         CUBIC  20
C                                                                       CUBIC  21
      ANG=(1.+DRATIO)*ALMAX                                             CUBIC  22
      CALL FULCAV(ANG,SIGMA,CAMBER,XL,CL,CPASS,S2,0)                    CUBIC  23
      SLOPE=(  S2-  S1)/DRATIO                                          CUBIC  24
C                                                                       CUBIC  25
C     CALCULATE CUBIC COEFFICIENTS AND CAVITY AREA                      CUBIC  26
C                                                                       CUBIC  27
      C1=SLOPE-2.*VALUE                                                 CUBIC  28
      C2=VALUE-C1                                                       CUBIC  29
      S   =(C1*RATIO+C2)*RATIO*RATIO                                    CUBIC  30
      RETURN                                                            CUBIC  31
      END                                                               CUBIC  32
```

```
      SUBROUTINE DERIV(NFIRST,NLAST,DX,Y,DYDX,D2YDX2,IFIRST,ISCND,IEND)  DERIV      2
      DIMENSION Y(1),DYDX(1),D2YDX2(1)                                   DERIV      3
      N1=NFIRST+1                                                        ADDGRAD   43
      N2=NLAST-1                                                         DERIV      5
      DO 2 J=N1,N2                                                       DERIV      6
      IF(IFIRST.NE.0) GO TO 1                                            DERIV      7
      DYDX(J)=.5*(-Y(J-1)+Y(J+1))/DX                                     DERIV      8
    1 IF (ISCND.NE.0) GO TO 2                                            DERIV      9
      D2YDX2(J)=(Y(J-1)-2.*Y(J)+Y(J+1))/(DX*DX)                          DERIV     10
    2 CONTINUE                                                           DERIV     11
      IF(IEND.NE.0) RETURN                                               DERIV     12
      IF(IFIRST.NE.0) GO TO 3                                            DERIV     13
      DYDX(NFIRST)=.5*(-3.*Y(NFIRST)+4.*Y(NFIRST+1)-Y(NFIRST+2))/DX      DERIV     14
      DYDX(NLAST)=.5*(3.*Y(NLAST)-4.*Y(NLAST-1)+Y(NLAST-2))/DX           DERIV     15
    3 IF(ISCND.NE.0) RETURN                                              DERIV     16
      D2YDX2(NFIRST)=D2YDX2(NFIRST+1)                                    DERIV     17
      D2YDX2(NLAST)=D2YDX2(NLAST-1)                                      DERIV     18
      RETURN                                                             DERIV     19
      END                                                                DERIV     20
```

```
 1                 SUBROUTINE ERROR(IER)                                  ERROR     2
             C                                                            ERROR     3
             C     SUBROUTINE ERROR IS USED TO PRINT ERROR MESSAGES AND STOP JOB  ERROR     4
             C                                                            ERROR     5
 5                 COMMON/UNITS/NIN,NOUT           ,DATE(5),TITLE(15)     ERROR     6
             C                                                            ERROR     7
                   CALL HEADIN                                            ERROR     8
                   WRITE(NOUT,100)IER                                     ERROR     9
             100   FORMAT(///21X,34HERROR ENCOUNTERED -- ERROR NUMBER=,I3,15H -- JOB  ERROR    10
 10               1ABORTED  )                                             ERROR    11
                   STOP                                                   ERROR    12
                   END                                                    ERROR    13
```

```
      SUBROUTINE EQPTS                                                  EQPTS      2
C                                                                       EQPTS      3
C                                                                       EQPTS      4
C     SUBROUTINE EQPTS USES THE MAPPING COEFFICIENTS AND THE NUMBER OF  FINAL4     2
C     POINTS (NPLOC) FOR INTEGRATION TO FIND THE POINTS ON THE BODY     EQPTS      6
C     CORRESPONDING TO POINT WITH EQUAL ANGLE INTERVALS IN THE          FINAL4     3
C     UNIT CIRCLE.                                                      EQPTS      8
C                                                                       EQPTS      9
C                                                                       EQPTS     10
      COMMON/SOLUT/NCOEF,PHI(100),A(10),AMAX,ICONV,NCOUNT               EQPTS     11
      COMMON/COORD/YLOC(100),ZLOC(100)                                  NEWFIX     5
      COMMON/UNITS/NIN,NOUT,DATE(5),TITLE(15)                           EQPTS     13
      COMMON/POINTS/NPLOC,XPT(100),RHOPT(100),PHIPT(100)                NEWFIX     6
      PI=4.*ATAN(1.0)                                                   EQPTS     15
      DPHI=PI/(NPLOC-1)                                                 EQPTS     16
      DO 10 I=1,NPLOC                                                   FINAL4     4
      YY=0.0                                                            EQPTS     23
      ZZ=0.0                                                            EQPTS     24
      DO 15 J=1,NCOEF                                                   EQPTS     25
      ARG=(3-2*J)*(I-1)*DPHI                                            EQPTS     26
      YY=YY+A(J)*COS(ARG)                                               EQPTS     27
      ZZ=ZZ+A(J)*SIN(ARG)                                               EQPTS     28
   15 CONTINUE                                                          EQPTS     29
      YLOC(I)=YY                                                        EQPTS     30
      ZLOC(I)=ZZ                                                        EQPTS     31
   10 CONTINUE                                                          EQPTS     36
      RETURN                                                            EQPTS     41
      END                                                               EQPTS     42
```

```
      SUBROUTINE FORIT(FNT,N,M,A,B,IER)
C
C     SUBROUTINE FORIT IS FROM THE IBM SCIENTIFIC SUBROUTINE PACKAGE
C
C     IT COMPUTES FOURIER COEFFICIENTS OF DATA POINTS IN THE INTERVAL
C     ZERO TO 2.*PI
C
      DIMENSION A(1),B(1),FNT(1)
C
C     CHECK FOR PARAMETER ERRORS
C
      IER=0
   20 IF(M) 30,40,40
   30 IER=2
      RETURN
   40 IF(M-N) 60,60,50
   50 IER=1
      RETURN
C
C     COMPUTE AND PRESET CONSTANTS
C
   60 CONTINUE
      AN=N
      COEF=2.0/(2.0*AN+1.0)
      PI=4.*ATAN(1.)
      CONST=PI*COEF
      S1=SIN(CONST)
      C1=COS(CONST)
      C=1.0
      S=0.0
      J=1
      FNTZ=FNT(1)
   70 U2=0.0
      U1=0.0
      I=2*N+1
   75 U0=FNT(I)+2.0*C*U1-U2
      U2=U1
      U1=U0
      I=I-1
      IF(I-1) 80,80,75
   80 A(J)=COEF *(FNTZ+ C*U1-U2)
      B(J)=COEF*S*U1
      IF(J-(M+1)) 90,100,100
   90 Q=C1*C-S1*S
      S=C1*S+S1*C
      C=Q
      J=J+1
      GO TO 70
  100 A(1)=A(1)*0.5
      RETURN
      END
```

```
      SUBROUTINE FOURAN(ARRAY,N,WORD1,WORD2,IPRINT)                          FINAL1     8
C                                                                            FOURAN     3
C     SUBROUTINE FOURAN IS A SERVICE ROUTINE USED TO FOURIER ANALYZE         FOURAN     4
C     SELECTED VARIABLES AND TO OUTPUT THE RESULTS FOR THE EFFECTS DUE       FOURAN     5
C     TO ALL BLADES                                                          FOURAN     6
C                                                                            FOURAN     7
      COMMON/CONST/PI,RHOF,U,OMEGA,DEPTH,PV,G,RAD                            FOURAN     8
      COMMON /FOURIR/NBLADE,NMULT,NFORIT                                     FOURAN     9
      COMMON/UNITS/NIN,NOUT          ,DATE(5),TITLE(15)                      FOURAN    10
      COMMON/DERIVT/DPDY(6,100),DPDZ(6,100),P(6,100)                         MERGDPN    4
      DIMENSION ARRAY(1),SINCOF(23),COSCOF(23)                               FIXDIP     1
C                                                                            FOURAN    12
C     WRITE HEADING FOR SELECTED VARIABLE                                    FOURAN    13
C                                                                            FOURAN    14
      IF(IPRINT .GT. 0) WRITE(NOUT,100) WORD1,WORD2,N                        FINAL1     9
C                                                                            FOURAN    16
C     FOURIER ANALYZE INPUT ARRAY FOR SINGLE BLADE                           FOURAN    17
C                                                                            FOURAN    18
      CALL FORIT(ARRAY,NFORIT,NMULT,COSCOF,SINCOF,IERT)                      FOURAN    19
C                                                                            FOURAN    20
C     CONVERT FOURIER COEFFICIENTS TO DESIRED OUTPUT UNITS AND ACCOUNT       FOURAN    21
C     FOR BLADE PHASING                                                      FOURAN    22
C                                                                            FOURAN    23
      CONST=1.0                                                              MERGDPN    5
      K=1                                                                    NEWFIX     8
      L=2                                                                    NEWFIX     9
      DO 1 J=1,NMULT,NBLADE                                                  FOURAN    24
      IHARM=J-1                                                              FOURAN    25
      SINVAL=SINCOF(J)*CONST*NBLADE                                          FOURAN    26
      COSVAL=COSCOF(J)*CONST*NBLADE                                          FOURAN    27
      AMP=SQRT(COSVAL*COSVAL+SINVAL*SINVAL)                                  FOURAN    28
      PHASE=ATAN2(SINVAL,COSVAL)*RAD                                         FOURAN    29
      IF(IPRINT .GT. 0) WRITE(NOUT,200)IHARM,COSVAL,SINVAL,AMP,PHASE         FINAL1    10
      IF(J .EQ. 1) GO TO 1                                                   MERGDPN    8
      IF(WORD1 .EQ. 4HDPTU) GO TO 2                                          MERGDPN    9
      P(K,N)=COSVAL                                                          MERGDPN   10
      P(L,N)=SINVAL                                                          MERGDPN   11
      GO TO 3                                                                MERGDPN   12
    2 IF(WORD2 .EQ. 4HT/DZ) GO TO 4                                          MERGDPN   13
      DPDY(K,N)=COSVAL                                                       MERGDPN   14
      DPDY(L,N)=SINVAL                                                       MERGDPN   15
      GO TO 3                                                                MERGDPN   16
    4 DPDZ(K,N)=COSVAL                                                       MERGDPN   17
      DPDZ(L,N)=SINVAL                                                       MERGDPN   18
    3 K=K+2                                                                  MERGDPN   19
      L=L+2                                                                  MERGDPN   20
    1 CONTINUE                                                               FOURAN    31
      RETURN                                                                 FOURAN    32
  100 FORMAT(//45X,A4,A4,I2/44X,10(1H*)                                      NEWFIX    10
     X                  //,20X,54HHARMONIC     REAL PART    IMAG PART    APPLI FOURAN  34
     1TUDE       PHASE   /69X,6H(DEG)  /)                                    FOURAN    35
  200 FORMAT(22X,I2,E16.4,2E12.4,F10.1)                                      FOURAN    36
      END                                                                    FOURAN    37
```

```
      SUBROUTINE FULCAV(ALPHA,SIGMA,CAMBER,XL,CL,CMASS,S,ITRANS)
C
C     SUBROUTINE FULCAV CALCULATES THE SOLUTION FOR A SUPERCAVITATING
C     PARABOLIC ARC FOIL BASED ON THE SOLUTION OF GEURST
C
      COMMON/CONST/PI,RHOF,U,OMEGA,DEPTH,PV,G,RAD
      COMMON/EXEC/TOL,NPTS,DTHETA,ISOL,NITMAX,NUMAX
C
C     INITIALIZE VARIABLES FOR FIRST PASS
C
      NITER=0
      XL=1.25
      DXL=40.0
      IFIRST=0
      GO TO 7
C
C     START SECOND PASS
C
    8 ERR1=ERR2
      POM1=SIGN(1.,ERR1)
      XL=41.25
    4 CONTINUE
      NITER=NITER+1
C
C     END JOB IF NUMBER OF ITERATIONS EXCEED MAXIMUM
C
      IF(NITER.GT.NITMAX) CALL ERROR(20)
    7 CONTINUE
C
C     SET UP REQUIRED PARAMETERS FOR SOLUTION
C
      B=1./SQRT(XL-1.)
      GAMMA=2.*ATAN(1./B)
      BETA=(PI-GAMMA)/4.
      SINDEL=SIN(GAMMA/2.)
      SINB=SIN(BETA)
      SIN3B=SIN(3.*BETA)
      SIN5B=SIN(5.*BETA)
      SIN7B=SIN(7.*BETA)
      COSDEL=COS(GAMMA/2.)
      COSB=COS(BETA)
      COS3B=COS(3.*BETA)
      COS5B=COS(5.*BETA)
      COS7B=COS(7.*BETA)
      FI10=-CAMBER*(2.*(1.-XL)*COSB+XL*SINDEL*(2.*COS3B+B*SIN3B))
      FI20=.5*CAMBER*((XL-2.)*COSB+SINDEL*(2.*(XL-1.)*COS3B
     1 +.5*B*(XL-2.)*SIN3B)+SINDEL*SINDEL*XL*(.75*(B*B-4.)*COS5B
     2 -3.*B*SIN5B))
      FI21=.5*CAMBER*(SINDEL*((-B+1.5*XL*B)*COS3B+(2.-4.*XL)*SIN3B)
     1 +SINDEL*SINDEL*(-3.*XL*B*COS5B-.75*XL*(B*B-4.)*SIN5B))
      FI30=.25*((XL-3.)*COSB+SINDEL*((XL-2.)*COS3B+.5*B*(XL-3.)*SIN3B)
     1 +3.*SINDEL*SINDEL*((.25*B*B+XL-1.)*COS5B+B*(.5*XL-1.)*SIN5B)
     2 +.625*XL*SINDEL**3*((6.*B*B-8.)*COS7B+B*(B*B-12.)*SIN7B))*CAMBER
      FI31=.25*CAMBER*SINDEL*(.5*B*(XL-1.)*COS3B+3.*SINDEL*(B*(1.5*XL
     1 -1.)*COS5B+((.25*B*B-1.)*(XL-1.)-XL)*SIN5B)+.625*XL*SINDEL
     1 *SINDEL*((-6.*B*B+8.)*SIN7B+B*(B*B-12.)*COS7B))
C
```

```
C     IF CALLED FROM TRANSITIONAL SUBPROGRAM DO NOT ITERATE
C
      IF(ITRANS.NE. 0) GO TO 5
C
C     CALCULATE ERROR
C
      ERR2=SINB*(FI10-FI20)-COSB*FI21+.25*COSDEL*(1.+SINDEL)*ALPHA
     1 -.125*SINDEL*(1.+SINDEL)*SIGMA
C
C     IF FIRST PASS - START SECOND PASS
C
      IF(IFIRST .EQ. 0 .AND. XL .EQ. 1.25) GO TO 8
C
C     TEST IF SOLUTION HAS CONVERGED
C
      DIFF=DXL/XL
      IF(ABS(DIFF).LT. TOL) GO TO 5
      POM2=SIGN(1.,ERR2)
      IF (IFIRST.EQ. 1) GO TO 1
      IFIRST=1
    1 CONTINUE
      IF(POM1.NE.POM2) GO TO 3
C
C     NO CHANGE IN SIGN OF ERROR - CONTINUE IN SAME DIRECTION
C
      XL=XL+DXL
      POM1=POM2
      GO TO 4
    3 CONTINUE
C
C     SIGN OF ERROR HAS CHANGED - GO BACK 1/2 STEP
C
      DXL=-DXL*.5
      XL=XL+DXL
      POM1=POM2
      GO TO 4
    5 CONTINUE
C
C     CALCULATE SOLUTION USING CONVERGED CAVITY LENGTH
C
      CL=PI*(4.*(COSB*(FI10-FI20)+SINB*FI21)/(COSDEL*COSDEL)
     1 +(ALPHA*SINDEL+.5*SIGMA*COSDEL)/(1.+SINDEL))
      CM=PI*((3.+SINDEL)*COSB*FI10-(7.+SINDEL)*COSB*FI20
     1 +(5.-SINDEL)*SINB*FI21+4.*COSB*FI30-4.*SINB*FI31)/COSDEL**4
     2 +.125*PI*((-1.+4.*SINDEL+2.*SINDEL*SINDEL)*ALPHA
     3 +COSDEL*(2.+SINDEL)*SIGMA)/(1.+SINDEL)**2
      CMASS=CM-.5*CL
     5  =.5*PI*((-3.+SINDEL)*SINB*FI10+(7.-SINDEL)*SINB*FI20+(5.+SINDEL
     1  )*COSB*FI21-4.*SINB*FI30-4.*COSB*FI31)/COSDEL**4*PI*(2.*COSDEL
     2  *(-2.+SINDEL)*ALPHA+.5*(1.+4.*SINDEL-2.*SINDEL*SINDEL)*SIGMA)/
     3  (4.*(1.-SINDEL))**2
      RETURN
      END
```

```
      SUBROUTINE GETA                                                   GETA      2
      COMMON/REPRES/NPTSI,X(100),Y(100),BEAM,DRAFT,AREA,DXSEG,GCTION    NEWFIX   11
      COMMON/SCLUT/NCOEF,PHI(100),A(10),AMAX,ICONV,NCOUNT               GETA      4
      DIMENSION AIJ(100),BI(10)                                         GETA      5
      DO 1 I=1,NCOEF                                                    GETA      6
      DO 1 J=1,NCOEF                                                    GETA      7
      INDEX=(I-1)*NCOEF+J                                               GETA      8
      SUM=0.0                                                           GETA      9
      DO 2 K=1,NPTSI                                                    GETA     10
      SUM=SUM+COS(2*(J-1)*PHI(K))                                       GETA     11
    2 CONTINUE                                                          GETA     12
      AIJ(INDEX)=SUM                                                    GETA     13
    1 CONTINUE                                                          GETA     14
      DO 3 I=1,NCOEF                                                    GETA     15
      SUM=0.0                                                           GETA     16
      DO 4 K=1,NPTSI                                                    GETA     17
      ARG=(3-2*I)*PHI(K)                                                GETA     18
      SUM=SUM+X(K)*COS(ARG)+Y(K)*SIN(ARG)                               GETA     19
    4 CONTINUE                                                          GETA     20
      BI(I)=SUM                                                         GETA     21
    3 CONTINUE                                                          GETA     22
      CALL SIMQ(AIJ,BI,NCOEF,KS)                                        GETA     23
      ICONV=1                                                           GETA     24
      DO 5 I=1,NCOEF                                                    GETA     25
      IF(ABS(A(I)-BI(I))/AMAX.GT. 0.01) ICONV=-1                        GETA     26
      A(I)=BI(I)                                                        GETA     27
    5 CONTINUE                                                          GETA     28
      RETURN                                                            GETA     29
      END                                                               GETA     30
```

```
      SUBROUTINE GETPHI                                                   GETPHI   2
      COMMON/REPRES/NPTS1,X(100),Y(100),BEAM,DRAFT,AREA,DXSEG,GCTION      NEWFIX  12
      COMMON/SOLUT/NCOEF,PHI(100),A(10),AMAX,ICONV,NCOUNT                 GETPHI   4
      PHI(1)=0.0                                                          GETPHI   5
      PHI(NPTS1)=-1.570796                                                FINAL1  11
      NPTSN1=NPTS1-1                                                      FINAL1  12
      DO 1 I=2,NPTSN1                                                     FINAL1  13
      XX=X(I)                                                             GETPHI   7
      YY=Y(I)                                                             GETPHI   8
      DPHI1=-0.0174532                                                    GETPHI   9
      IF(I.GT.2) DPHI1=(PHI(I-1)-PHI(I-2))/10.                            GETPHI  10
      PHIW=PHI(I-1)                                                       GETPHI  11
      CALL INTERP(XX,YY,DPHI1,PHIW)                                       GETPHI  12
      PHIW=PHIW-2.*DPHI1                                                  GETPHI  13
      DPHI2=DPHI1/10.                                                     GETPHI  14
      CALL INTERP(XX,YY,DPHI2,PHIW)                                       GETPHI  15
      PHIW=PHIW-2.*DPHI2                                                  GETPHI  16
      DPHI3=DPHI2/10.                                                     GETPHI  17
      CALL INTERP(XX,YY,DPHI3,PHIW)                                       GETPHI  18
      PHI(I)=PHIW-DPHI3                                                   GETPHI  19
    1 CONTINUE                                                            GETPHI  20
      RETURN                                                              GETPHI  21
      END                                                                 GETPHI  22
```

```
            SUBROUTINE HEADIN                                                  HEADIN     2
      C                                                                        HEADIN     3
      C     SUBROUTINE HEADIN IS USED TO PRINT THE DATE AND TITLE AT PAGE TOP  HEADIN     4
      C                                                                        HEADIN     5
            COMMON/UNITS/NIN,NOUT             ,DATE(5),TITLE(15)               HEADIN     6
      C                                                                        HEADIN     7
            WRITE(NOUT,200)DATE,TITLE                                          HEADIN     8
      200   FORMAT(1H1/30X,28HPROPELLER CAVITATION PROGRAM/29X,30(1H*)         HEADIN     9
           1                                      //20X,5A4,15A4//)            HEADIN    10
            RETURN                                                             HEADIN    11
            END                                                                HEADIN    12
```

```
                 SUBROUTINE INLDS(  NOMAX)                                    INLDS        2
          C                                                                   INLDS        3
          C      SUBROUTINE INLDS IS USED TO READ THE MODAL LOADING SOLUTION FOR INLDS     4
          C      THE NON-CAVITATING PROPELLER AND TO CALCULATE THE SPANWISE   INLDS        5
          C      LOADING FOR EACH HARMONIC                                    INLDS        6
          C                                                                   INLDS        7
                 COMMON/FORCES/XLO,XLREAL(22),XLIMAG(22)                      INLDS        8
                 COMMON/UNITS/NIN,NOUT                  ,DATE(5),TITLE(15)    INLDS        9
          C                                                                   INLDS       10
          C      READ TOTAL STEADY LOADING                                    INLDS       11
          C                                                                   INLDS       12
                 READ(NIN,100)XLO                                             INLDS       13
          C                                                                   INLDS       14
          C      LOOP OVER UNSTEADY HARMONICS                                 INLDS       15
          C                                                                   INLDS       16
                 DO 1 J=1,NOMAX                                               INLDS       17
                 READ(NIN,100) XLR1,XLIMG1,XLR2,XLIMG2                        INLDS       18
                 XLREAL(J)=XLR1+.5*XLR2                                       INLDS       19
                 XLIMAG(J)=XLIMG1+.5*XLIMG2                                   INLDS       20
          1      CONTINUE                                                     INLDS       21
          100    FORMAT(8F10.0)                                               INLDS       22
                 RETURN                                                       INLDS       23
                 END                                                          INLDS       24
```

```
      SUBROUTINE INTERP(XX,YY,DPHI,PHIW)                                INTERP    2
      COMMON/SOLUT/NCOEF,PHI(100),A(10),AMAX,ICONV,NCOUNT               INTERP    3
      COMMON/UNITS/NIN,NOUT,DATE(5),TITLE(15)                           FINAL1   14
    5 K=-1                                                              INTERP    4
      EOLD=0.0                                                          INTERP    5
      ISLOPE=1                                                          INTERP    6
      PHI1=PHIW                                                         INTERP    7
    1 CONTINUE                                                          INTERP    8
      PHIW=PHI1+K*DPHI                                                  INTERP    9
    7 SUM1=0.0                                                          INTERP   10
      SUM2=0.0                                                          INTERP   11
      DO 2 L=1,NCOEF                                                    INTERP   12
      ARG=(3-2*L)*PHIW                                                  INTERP   13
      SUM1=SUM1+A(L)*COS(ARG)                                           INTERP   14
      SUM2=SUM2+A(L)*SIN(ARG)                                           INTERP   15
    2 CONTINUE                                                          INTERP   16
      ENEW=(XX-SUM1)**2+(YY-SUM2)**2                                    INTERP   17
      IF(EOLD.GT.ENEW) ISLOPE=-1                                        INTERP   18
      IF(ISLOPE.GT. 0) GO TO 3                                          INTERP   19
      IF(EOLD.LE.ENEW) RETURN                                           INTERP   20
    3 CONTINUE                                                          INTERP   21
      K=K+1                                                             INTERP   22
      IF(K .GT. 100) WRITE(NOUT,100)                                    FINAL1   15
      IF(K .GT. 100) STOP 10                                            FINAL1   16
      EOLD=ENEW                                                         INTERP   24
      GO TO 1                                                           INTERP   25
  100 FORMAT(//,5X,64HTHE TRANSFORMATION COEFFICIENTS FOR THIS SECTION D FINAL1   17
     1O NOT CONVERGE,/,5X,64(1H*)  )                                    FINAL1   18
      END                                                               INTERP   26
```

```
      SUBROUTINE INPUT                                                  INPUT      2
C                                                                       INPUT      3
C     SUBROUTINE INPUT READS INPUT AND INITIALIZES VARIOUS CONSTANTS    INPUT      4
C                                                                       INPUT      5
      COMMON/CONST/PI,RHOF,U,OMEGA,DEPTH,PV,G,RAD                       INPUT      6
      COMMON/EXEC/TOL,        NPTS,DTHETA,ISOL,NITMAX        ,NOMAX     INPUT      7
      COMMON /FOURIR/NBLADE,NMULT,NFORIT                                INPUT      8
      COMMON/GEOM/        NRAD,RO,RIND,ORND,PSKEW(8),PCHORD(8)          INPUT      9
      COMMON/UNITS/NIN,NOUT                 ,DATE(5),TITLE(15)          INPUT     11
      COMMON/PRINT/IPRESS,IPGRAD                                        FINAL1    19
      DATA WORD1,WORD2/4H YES ,4H NO /                                  INPUT     12
C                                                                       INPUT     13
C     SET UP UNIT NUMBERS FOR INPUT AND OUTPUT FILES                    INPUT     14
C                                                                       INPUT     15
      NIN=5                                                             INPUT     16
      NOUT=6                                                            INPUT     17
      WORD=WORD1                                                        INPUT     18
C                                                                       INPUT     19
C     READ INPUT                                                        INPUT     20
C                                                                       INPUT     21
      READ(NIN,100)DATE,TITLE                                           INPUT     22
      READ(NIN,101) NBLADE,NRAD,NOMAX                                   NEWFIX    13
      READ(NIN,101) ISOL,IPRESS,IPGRAD                                  FINAL1    20
      IF(ISOL.EQ.0)WORD=WORD2                                           INPUT     25
      READ(NIN,102)RO,RIND,ORND,RPM,U                                   INPUT     26
      READ(NIN,102)(PCHORD(J),J=1,NRAD)                                 INPUT     27
      READ(NIN,102)(PSKEW (J),J=1,NRAD)                                 INPUT     28
      READ(NIN,102)DEPTH,PV,RHOF                                        INPUT     29
C                                                                       INPUT     30
C     INITIALIZE VARIABLES                                              INPUT     31
C                                                                       INPUT     32
      TOL=.001                                                          INPUT     33
      NITMAX=50                                                         INPUT     34
      PI=4.*ATAN(1.)                                                    INPUT     35
      RAD=180./PI                                                       INPUT     36
      G=32.17                                                           INPUT     37
      NPTS=181                                                          INPUT     38
      NFORIT=(NPTS-1)/2                                                 INPUT     39
      NMULT=NBLADE*3+1                                                  INPUT     40
      OMEGA=RPM*PI/30.                                                  INPUT     41
      DTHETA=2.*PI/(NPTS-1)                                             INPUT     42
      CALL READIN                                                       INPUT     43
      WRITE(NOUT,201)RO,NRAD,RIND,ORND                                  INPUT     44
C                                                                       INPUT     45
C     PRINT INPUT INFORMATION                                           INPUT     46
C                                                                       INPUT     47
      WRITE(NOUT,204)        DEPTH,PV,RHOF                              INPUT     48
      WRITE(NOUT,202)RPM,U,WORD                                         INPUT     49
      WRITE(NOUT,203) NBLADE,NOMAX                                      NEWFIX    14
C                                                                       INPUT     51
C     TEST FOR INPUT ERRORS                                             INPUT     52
C                                                                       INPUT     53
      IF(NRAD.LT.1 .OR. NRAD.GT.8)CALLERROR(1)                          INPUT     54
      IF(NBLADE.LT.1 .OR. NBLADE.GT.7) CALL ERROR(2)                    INPUT     55
      IF(NOMAX.LT.NBLADE+1 .OR. NOMAX.GT.22)CALL ERROR(3)               INPUT     56
      IF(RIND.LE. 0.0 .OR. (RIND+(NRAD-1)*ORND).GT. 1.0)CALL ERROR(5)   INPUT     58
      IF(ORND.LE. 0.0) CALL ERROR(6)                                    INPUT     59
```

```
      C                                                                     INPUT      60
      C    PRINT PROPELLER SPANWISE INPUT                                   INPUT      61
      C                                                                     INPUT      62
           WRITE(NOUT,205)                                                  INPUT      63
           DO 1 J=1,NRAD                                                    INPUT      64
           RND=RIND+(J-1)*DRND                                              INPUT      65
           WRITE(NOUT,209)RRD,PCHORD(J),PSKEW(J)                            INPUT      66
      1    CONTINUE                                                         INPUT      67
           RETURN                                                           INPUT      77
      100  FORMAT(5A4,15A4)                                                 INPUT      80
      101  FORMAT(16I5)                                                     INPUT      81
      102  FORMAT(8F10.0)                                                   INPUT      82
      201  FORMAT( 5X,17HPROP RADIUS (FT)=,F6.2,3X,24HNUMBER OF RADIAL STRIPS INPUT    83
          1=,I2,3X,30HNON-DIM RADIUS OF FIRST STRIP=,F5.3,3X,27HNON-DIM INCRE INPUT    84
          2MENT IN RADII=,F5.3/ )                                          INPUT      85
      202  FORMAT( 5X,9HPROP RPM=,F7.2,3X,17HSHIP SPEED (FPS)=,F6.2,        INPUT      86
          1  3X,26HPRINT OPTION FOR SOLUTION=,A4/)                          INPUT      87
      203  FORMAT( 5X,13HNO OF BLADES=,I3,3X,51HNO OF HARMONICS USED IN UNSTE INPUT    88
          1ADY LIFT CALCULATIONS=,I3)                                      NEWFIX     15
      204  FORMAT( 5X,                                                      INPUT      90
          1 3CHDEPTH TO PROP CENTERLINE (FT)=,F6.2,3X,18HVAPOR PRESS (PSF)=, INPUT     91
          3 F6.2,3X,28HWATER DENSITY (SLUGS/FT**3)=,F5.2/)                  INPUT      92
      205  FORMAT(//29X,24HPROPELLER SPANWISE INPUT  /28X,26(1H*)           INPUT      93
          1        //30X,23HR/RO      CHORD      SKEW                       INPUT      94
          1/ 30X,    23H        (FT)       (RAD)   //)                      INPUT      95
      209  FORMAT(25X,F9.3,F10.3,F9.3)                                      INPUT     100
           END                                                              INPUT     102
```

```
      SUBROUTINE INPUT2                                                  INPUT2     2
C                                                                        INPUT2     3
C     THIS ROUTINE READS THE INPUT FOR EVERY SECTION GEOMETRY            INPUT2     4
C                                                                        INPUT2     5
      COMMON/REPRES/NPTS1,X(100),Y(100),BEAM,DRAFT,AREA,DXSEC,GCTION     INPUT2     6
      COMMON/IDENTF/SEC                                                  FINAL4     5
      COMMON/COORD/YLOC(100),ZLOC(100)                                   INPUT2     7
      COMMON/CONST/PI,RHOF,U,OMEGA,DEPTH,PV,G,RAD                        INPUT2     8
      COMMON/GEOM/NRAD,RG,RIND,DRND,PSKEW(8),PCHORD(8)                   INPUT2     9
      COMMON/POINTS/NPLOC,XPT(100),RHOPT(100),PHIPT(100)                 INPUT2    10
      COMMON/UNITS/NIN,NOUT,DATE(5),TITLE(15)                            INPUT2    11
C                                                                        INPUT2    12
C     READ THE NUMBER OF POINTS DESCRIBING HALF THE SECTION AND THE      INPUT2    13
C     NUMBER OF LOCATIONS DESIRED FOR PRESSURE CALCULATIONS.             INPUT2    14
C                                                                        INPUT2    15
      READ(NIN,100) NPTS1,NPLOC                                          INPUT2    16
C                                                                        INPUT2    17
      IF(NPTS1 .LT. 0) STOP                                              INPUT2    18
      IF(NPLOC .EQ. 0) CALL ERROR(7)                                     INPUT2    19
      IF(NPLOC .GT. 99) CALL ERROR(4)                                    INPUT2    20
      NX=(NPLOC-1)/2                                                     INPUT2    21
      NPLOX=(2*NX)+1                                                     INPUT2    22
      IF(NPLOX .NE. NPLOC) GO TO 40                                      INPUT2    23
   12 CONTINUE                                                           INPUT2    24
C                                                                        INPUT2    25
      READ(NIN,110)SEC,BEAM,DRAFT,AREA,DXSEC,XDIST,GCTION                FINAL4     6
      WRITE(NOUT,200)                                                    INPUT2    27
      XSEC=ABS(SEC)                                                      FINAL6     1
      WRITE(NOUT,210) XSEC,XDIST                                         FINAL6     2
      WRITE(NOUT,200)                                                    INPUT2    29
      WRITE(NOUT,180)NPTS1                                               INPUT2    30
      WRITE(NOUT,170) BEAM,DRAFT,AREA                                    INPUT2    31
      WRITE(NOUT,175) DXSEC,GCTION                                       FINAL1    22
      WRITE(NOUT,160)                                                    INPUT2    32
      BEAM=BEAM/2.0                                                      INPUT2    35
C                                                                        INPUT2    36
C     READ THE COORDINATES OF THE POINTS DESCRIBING THE HALF SECTION     INPUT2    37
C                                                                        INPUT2    38
      READ(NIN,110) (X(I),I=1,NPTS1)                                     INPUT2    39
      READ(NIN,110) (Y(I),I=1,NPTS1)                                     INPUT2    40
C                                                                        INPUT2    41
C     EVALUATE THE TRANSFORMATION COEFFICIENTS                           INPUT2    42
C                                                                        INPUT2    43
      CALL MAPS                                                          INPUT2    44
C                                                                        INPUT2    45
C     CALCULATE RHOPT(I),PHIPT(I)                                        INPUT2    46
C                                                                        INPUT2    47
      DO 15 I=1,NPLOC                                                    INPUT2    48
      ZBAR=ZLOC(I)+DEPTH                                                 INPUT2    49
      RHOPT(I)=SQRT(YLOC(I)*YLOC(I)+ZBAR*ZBAR)/RO                        INPUT2    50
   15 PHIPT(I)=ATAN2(-YLOC(I),ZBAR)*RAD                                  INPUT2    51
C                                                                        INPUT2    52
C                                                                        INPUT2    54
      DO 2 J=1,NPLOC                                                     INPUT2    57
      XPT(J)=-XDIST                                                      FINAL4     8
    2 CONTINUE                                                           INPUT2    60
      RETURN                                                             INPUT2    61
```

```
   40 WRITE(NOUT,998)                                                  INPUT2   65
      WRITE(NOUT,999) NPLOC,NPLOX                                      INPUT2   66
      NPLOC=NPLOX                                                      INPUT2   67
      GO TO 12                                                         INPUT2   68
  10C FORMAT(5I10)                                                     INPUT2   69
  110 FORMAT(8F10.4)                                                   INPUT2   70
  160 FORMAT(/7,5X,80HTHE FOLLOWING IS A TABLE OF THE COORDINATES INPUT FINAL1   23
     1ANC CALCULATED BY THE PROGRAM )                                  FINAL1   24
  170 FORMAT(5X,29HTHE BEAM FOR THIS SECTION IS ,F10.4,17HFT, THE DRAFT FINAL4    9
     1IS ,F10.4,20H FT AND THE AREA IS ,F10.4,12H FT SQUARED )         FINAL4   10
  175 FORMAT(/,5X, 42H AT THIS STATION THE SECTION THICKNESS IS ,F10.3, FINAL1  25
     143HFT , THE MODAL WEIGHTING FUNCTION VALUE IS ,F10.3)            FINAL1   26
  18C FORMAT(/,5X,10HTHERE ARE ,I2,37H POINTS TO DESCRIBE THIS HALF SECT FINAL1 27
     1ION )                                                            FINAL1   28
  200 FORMAT(//,1H )                                                   INPUT2   79
  21C FORMAT(1H1,//5X,42HTHE FOLLOWING ARE THE RESULTS FOR SECTION ,   FINAL4   11
     1F5.2,9H LOCATED ,F10.3,28H FT FORWARD OF THE PROPELLER/3X,99(1H*)) FINAL4 12
  998 FORMAT(1H1,25(/),20(1H*),9H WARNING ,20(1H*))                    FINAL4   13
  999 FORMAT(/,50H YOU HAVE INPUT AN EVEN NUMBER FOR NPLOC EQUAL TO ,I2, FINAL4 14
     140H THE NUMBER TO BE USED AS NPLCC WILL BE ,I2)                  FINAL4   15
      END                                                              INPUT2   91
```

```
           SUBROUTINE MAPS                                                MAPS      2
           COMMON/SCLUT/NCOEF,PHI(100),A(10),AMAX,ICONV,NCOUNT            MAPS      3
           COMMON/REPRES/NPTS1,X(100),Y(100),BEAM,DRAFT,AREA,DXSEC,GCTION NEWFIX   16
           COMMON/UNITS/NIN,NOUT,DATE(5),TITLE(15)                        MAPS      5
           PI=4.*ATAN(1.)                                                 MAPS      7
     C     LEWIS  FORM AS FIRST GUESS                                     MAPS      9
           A(2)=0.5*(BEAM-DRAFT)                                          MAPS     10
           A(3)=0.25*(-(BEAM+DRAFT)+SQRT((BEAM+DRAFT)**2+8.*(BEAM*DRAFT-2.*AR MAPS 11
          1EA/PI)))                                                       MAPS     12
           A(1)=0.5*(BEAM+DRAFT)-A(3)                                     MAPS     13
           DO 1 J=4,10                                                    MAPS     14
           A(J)=0.0                                                       MAPS     15
     1     CONTINUE                                                       MAPS     16
           NMAX=8                                                         MAPS     17
           WRITE(NOUT,120)                                                MAPS     18
           DO 4 N    =4,NMAX                                              MAPS     19
           NCOEF=N                                                        MAPS     20
           NCOUNT=0                                                       MAPS     21
     12    CONTINUE                                                       MAPS     22
           NCOUNT=NCOUNT+1                                                MAPS     23
           AMAX=0.0                                                       MAPS     24
           DO 15 J=1,NCOEF                                                MAPS     25
           AMAX=AMAX1(AMAX,A(J))                                          MAPS     26
     15    CONTINUE                                                       MAPS     27
           CALL GETPHI                                                    MAPS     28
           CALL GETA                                                      MAPS     29
           DO 3 J=1,NPTS1                                                 MAPS     30
           XX=0.0                                                         MAPS     31
           YY=0.0                                                         MAPS     32
           DO 2 I=1,NCOEF                                                 MAPS     33
           ARG=(3-2*I)*PHI(J)                                             MAPS     34
           XX=XX+A (I)*COS(ARG )                                          MAPS     35
           YY=YY+A(I)*SIN(ARG)                                            MAPS     36
     2     CONTINUE                                                       MAPS     37
           IF(NCOEF .LT. 8) GO TO 3                                       MAPS     38
           IF(NCOUNT .EQ. 2) GO TO 5                                      MAPS     39
           IF(NCOUNT .EQ. 10) GO TO 5                                     MAPS     40
           GO TO 3                                                        MAPS     41
         5 WRITE(NOUT,110) J,PHI(J),X(J),XX,Y(J),YY                       MAPS     42
     3     CONTINU E                                                      MAPS     43
           IF(N .EQ.NMAX) CALL EQPTS                                      MAPS     44
           IF(NCOUNT.EQ.10) GO TO 4                                       MAPS     45
           IF(NCOUNT.EQ.1) GO TO 12                                       MAPS     46
           IF(ICONV.LT. 0) GO TO 12                                       MAPS     47
     4     CONTINUE                                                       MAPS     48
           RETURN                                                         FINAL1   31
       110 FORMAT(10X,I2,10X,F10.6,5X,F10.6,11X,F10.6,12X,F10.6,12X,F10.6) MAPS    49
       120 FORMAT(//,5X,13HPOINT NUMBER ,5X,10HANGLE PHI ,5X,9H INPUT Y ,10X, FINAL4 16
          113HCALCULATED Y ,10X,9H INPUT Z ,10X,13H CALCULATED Z,//)      FINAL4   17
           END                                                            MAPS     53
```

```
      SUBROUTINE PARCAV(ALPHA,SIGMA,CAMBER,XL,CL,CMASS,S,ITRANS)        PARCAV   2
C                                                                       PARCAV   3
C     SUBROUTINE PARCAV CALCULATES THE SOLUTION FOR A PARTIALLY         PARCAV   4
C     CAVITATING PARABOLIC FOIL BASED ON THE SOLUTION OF GEURST         PARCAV   5
C                                                                       PARCAV   6
      COMMON/CONST/PI,RHOF,U,OMEGA,DEPTH,PV,G,RAD                       PARCAV   7
      COMMON/EXEC/TOL,        NPTS,DTHETA,ISOE,NITMAX,        ,NOMAX    PARCAV   8
C                                                                       PARCAV   9
C     INITIALIZE VARIABLES FOR FIRST PASS                               PARCAV  10
C                                                                       PARCAV  11
      NITER=0                                                           PARCAV  12
      XL=.5                                                             PARCAV  13
      DXL=-.225                                                         PARCAV  14
      IFIRST=0                                                          PARCAV  15
      GO TO 7                                                           PARCAV  16
C                                                                       PARCAV  17
C     START SECOND PASS                                                 PARCAV  18
C                                                                       PARCAV  19
    8 ERR1=ERR2                                                         PARCAV  20
      POM1=SIGN(1.,ERR1)                                                PARCAV  21
      XL=.05                                                            PARCAV  22
    4 CONTINUE                                                          PARCAV  23
      NITER=NITER+1                                                     PARCAV  24
C                                                                       PARCAV  25
C     END JOB IF NUMBER OF ITERATIONS EXCEED MAXIMUM                    PARCAV  26
C                                                                       PARCAV  27
      IF(NITER.GT.NITMAX) CALL ERROR(10)                                PARCAV  28
    7 CONTINUE                                                          PARCAV  29
C                                                                       PARCAV  30
C     SET UP REQUIRED PARAMETERS FOR SOLUTION                           PARCAV  31
C                                                                       PARCAV  32
      SINVAL=SQRT(XL)                                                   PARCAV  33
      COSVAL=SQRT(1-XL)                                                 PARCAV  34
C                                                                       PARCAV  35
C     IF CALLED FROM TRANSITIONAL SUBPROGRAM DO NOT ITERATE             PARCAV  36
C                                                                       PARCAV  37
      IF(ITRANS .NE. 0 ) GO TO 5                                        PARCAV  38
C                                                                       PARCAV  39
C     CALCULATE ERROR                                                   PARCAV  40
C                                                                       PARCAV  41
      ERR2=ALPHA*(1.+COSVAL)*SINVAL-.5*SIGMA*(1.-COSVAL)*COSVAL+        PARCAV  42
     1 CAMBER*COSVAL*SINVAL**3                                          PARCAV  43
C                                                                       PARCAV  44
C     IF FIRST PASS - START SECOND PASS                                 PARCAV  45
C                                                                       PARCAV  46
      IF(IFIRST.EQ. 0 .AND. XL .EQ. 0.50) GO TO 8                       PARCAV  47
C                                                                       PARCAV  48
C     TEST IF SOLUTION HAS CONVERGED                                    PARCAV  49
C                                                                       PARCAV  50
      DIFF=DXL/XL                                                       PARCAV  51
      IF(ABS(DIFF).LT. TOL) GO TO 5                                     PARCAV  52
      POM2=SIGN(1.,ERR2)                                                PARCAV  53
      IF (IFIRST.EQ. 1) GO TO 1                                         PARCAV  54
      IFIRST=1                                                          PARCAV  55
      IF(POM1.EQ.POM2) GO TO 2                                          PARCAV  56
      GO TO 3                                                           PARCAV  57
    1 CONTINUE                                                          PARCAV  58
```

```
      IF(POM1.NE.POM2) GO TO 3
C
C     NO CHANGE IN SIGN OF ERROR - CONTINUE IN SAME DIRECTION
C
      XL=XL+DXL
      POM1=POM2
      GO TO 4
    3 CONTINUE
C
C     SIGN OF ERROR HAS CHANGED - GO BACK 1/2 STEP
C
      DXL=-DXL*.5
      XL=XL+DXL
      POM1=POM2
      GO TO 4
    2 IF(ABS(ERR1).LT. ABS(ERR2))GO TO 20
C
C     SOLUTION LIES BETWEEN 0.0 AND .05 REPLACE BY 0.0
C
      XL=0.0
      CL=0.0
      CMASS=0.0
      S=0.0
      RETURN
   20 XL=.50
    5 CONTINUE
C
C     CALCULATE SOLUTION USING CONVERGED CAVITY LENGTH
C
      COSVAL=SQRT(1-XL)
      SINVAL=SQRT(XL)
      COSPLS=1.+COSVAL
      COSMNS=1.-COSVAL
      CL=PI*(ALPHA*COSPLS*COSVAL+.5*SIGMA*COSMNS*SINVAL+.5*CAMBER
     1 *COSPLS*(COSPLS+2.*COSVAL*COSMNS))
      CM=.125*PI*(ALPHA*COSPLS*COSPLS*(-1.+8.*COSVAL-6.*COSVAL*COSVAL)
     1 -SIGMA*COSMNS*SINVAL*COSPLS*(-2.+3.*COSVAL)+2.*CAMBER*COSPLS
     2*(1.+COSVAL*(2.+COSVAL*(4.+COSVAL*(-5.+COSVAL*(-4.+4.*COSVAL))))))
      CMASS=CM-.5*CL
      S=0.0
      RETURN
      END
```

```
      SUBROUTINE PROIST                                                 PROIST     2
C                                                                       PROIST     3
C                                                                       PROIST     4
C     THIS SUBROUTINE EVALUATES THE PRESSURE DISTRIBUTION ON THE UNIT   PROIST     5
C     FLAT PLATE BY SOLVING A SINGULAR INTEGRAL EQUATION                FINAL4    18
C                                                                       PROIST     7
      COMMON/POINTS/NPLOC,XPT(100),RHOPT(100),PHIPT(100)                NEWFIX    19
      COMMON/UNITS/NIN,NOUT,DATE(5),TITLE(15)                           PROIST     9
      COMMON/NCRGRD/DPDN(100),COSVAL(100),SINVAL(100),DPHI,NPASS,P3(100) NEWFIX   20
      DIMENSION G(200),G1(200),SINCOF(100),COSCOF(100)                  FINAL5     1
      DTHETA=-DPHI                                                      LASTFIX    1
      G(1)=0.0                                                          PROIST    14
      G(2*NPLOC-1)=0.0                                                  PROIST    15
      NPLOC1=NPLOC-1                                                    PROIST    16
      DO 10 N=2,NPLOC                                                   PROIST    17
      G(N)=G(N-1)+(DPDN(NPLOC+1-N)*SIN((NPLOC-N)*DTHETA)+DPDN(NPLOC-N)* PROIST    18
     1SIN((NPLOC-1-N)*DTHETA))*DTHETA/2.                                PROIST    19
      G(2*NPLOC-N)=G(N)                                                 PROIST    20
   10 CONTINUE                                                          PROIST    21
      DO 11 I=1,NPLOC                                                   PROIST    22
      G1(I)=G(NPLOC+1-I)                                                PROIST    23
   11 G1(2*NPLOC-I)=G1(I)                                               PROIST    24
C                                                                       PROIST    25
C                                                                       PROIST    32
C     FOURIER ANALYSIS                                                  PROIST    33
C                                                                       PROIST    34
      CALL FORIT(G1,NPLOC1,NPLOC1,COSCOF,SINCOF,IER)                    FINAL5     2
      DO 20 NHARM=1,NPLOC                                               PROIST    36
      SINVAL(NHARM)=SINCOF(NHARM)                                       PROIST    37
      COSVAL(NHARM)=COSCOF(NHARM)                                       PROIST    38
      P3(NHARM)=0.0                                                     FINAL1    32
   20 CONTINUE                                                          PROIST    39
      DO 35 K=1,NPLOC                                                   PROIST    47
      DO 30 NHARM=2,NPLOC                                               NEWFIX    23
      P3(K)=P3(K)-COSVAL(NHARM)*SIN((NHARM-1)*(K-1)*DTHETA)             NEWFIX    24
   30 CONTINUE                                                          PROIST    50
   35 CONTINUE                                                          PROIST    52
      RETURN                                                            PROIST    53
      END                                                               PROIST    58
```

```
      SUBROUTINE PRESS                                                   PRESS       2
C                                                                        PRESS       3
C     SUBROUTINE PRESS CALCULATES RADIATED PRESSURES DUE TO CAVITY       FINAL4     19
C     GEOMETRY AND LIFT VARIATIONS.                                      FINAL4     20
C                                                                        PRESS       7
      COMMON/CONST/PI,RHCF,U,OMEGA,DEPTH,PV,G,RAD                        PRESS       8
      COMMON/EXEC/TOL,        NPTS,DTHETA,ISOL,NITMAX       ,NOMAX       PRESS       9
      COMMON/GEOM/       NRAD,RO,RIND,DRND,PSKEW(8),PCHORD(8)            PRESS      10
      COMMON/POINTS/NPLOC,XPT(100),RHOPT(100),PHIPT(100)                 NEWFIX     26
      COMMON /SOLUTN/CLIFT(8,181),VEL(8)                                 ADDGRAD    44
      COMMON/UNITS/NIN,NCUT                   ,DATE(5),TITLE(15)         PRESS      13
      COMMON/PRINT/IPRESS,IPGRAD                                         FINAL1     33
      COMMON/GRADS/DXLDTH(8,181),DSDTH(8,181),DZSDTH(8,181),NREG(8),     ADDGRAD    45
     1P(181),DPDY(181),DPDZ(181),NX1(8,30),NX2(8,30),XL(8,181)           ADDGRAD    46
      DIMENSION WORK(181)                                                NEWFIX     27
      DIMENSION PFREE(181)                                               PREFREE     1
      DATA WORD1/4HGAUG/                                                 PRESS      17
C                                                                        PRESS      18
C                                                                        PRESS      20
      DO 60 N=1,NPLOC                                                    ADDGRAD    54
      DO 15 I=1,181                                                      ADDGRAD    55
      PFREE(I)=0.0                                                       PREFREE     2
      P(I)=0.0                                                           ADDGRAD    56
      DPDY(I)=0.0                                                        ADDGRAD    57
      DPDZ(I)=0.0                                                        ADDGRAD    58
   15 CONTINUE                                                           ADDGRAD    59
      WORD1=4HGAUG                                                       ADDGRAD    60
      X=XPT(N)                                                           ADDGRAD    61
      RHO=RHOPT(N)*RO                                                    ADDGRAD    62
      PHI=PHIPT(N)/RAD                                                   ADDGRAD    63
      SINPHI=SIN(PHI)                                                    ADDGRAD    64
      COSPHI=COS(PHI)                                                    ADDGRAD    65
      DO 80 K=1,NRAD                                                     ADDGRAD    66
      NREGNS=NREG(K)                                                     ADDGRAD    67
      IF(NREGNS .EQ.0) GO TO 80                                          ADDGRAD    68
      RND=RIND+(K-1)*DRND                                                ADDGRAD    69
      R=RND*RO                                                           ADDGRAD    70
      DR=DRND*RO                                                         ADDGRAD    71
      PCONST=OMEGA*RHCF*DR/(4.*PI)                                       ADDGRAD    72
      SKEW=PSKEW(K)                                                      ADDGRAD    73
      CHORD=PCHORD(K)                                                    ADDGRAD    74
      DO 70J=1,NREGNS                                                    ADDGRAD    75
      NFIRST=NX1(K,J)                                                    ADDGRAD    76
      NLAST=NX2(K,J)                                                     ADDGRAD    77
      DO 70 I=NFIRST,NLAST                                               ADDGRAD    78
      THETA=(I-1)*DTHETA                                                 ADDGRAD    79
      SRCANG=THETA+SKEW+.5*(XL(K,I)-CHORD)/R                             ADDGRAD    80
      DIST=SQRT(X*X+R*R+RHO*RHO-2.*R*RHO*COS(SRCANG-PHI))                ADDGRAD    81
      PFACTR=PCONST/DIST**2                                              ADDGRAD    82
      COSARG=COS(SRCANG-PHI)                                             ADDGRAD    83
      SINARG=SIN(SRCANG-PHI)                                             ADDGRAD    84
      COSBET=COS(SRCANG)                                                 ADDGRAD    85
      SINBET=SIN(SRCANG)                                                 ADDGRAD    86
      ARG1=U*X-OMEGA*RHO*(R+.5*DXLDTH(K,I))*SINARG                       ADDGRAD    87
      TERM1=-((3./DIST**2)*DSDTH(K,I)*ARG1+OMEGA*DZSDTH(K,I))            ADDGRAD    88
      TERM2=(1./DIST)*DSDTH(K,I)*OMEGA*(R+.5*DXLDTH(K,I))                ADDGRAD    89
      P1=(ARG1*DSDTH(K,I)/DIST**3+OMEGA*DZSDTH(K,I)/DIST)*PCONST         ADDGRAD    90
```

```
      DRDRHO=(RHO-R*COSARG)/DIST                                        ADDGRAD   91
      DRDPHI=-RHO*R*SINARG/DIST                                         ADDGRAD   92
      DPDRHO=PFACTR*(TERM1*DRDRHO+TERM2*(-SINARG))                      ADDGRAD   93
      DPDPHI=PFACTR*(TERM1*DRDPHI+TERM2*RHO*COSARG)                     ADDGRAD   94
      DP1DY=-(SINPHI*DPDRHO+COSPHI*DPDPHI/RHO)                          ADDGRAD   95
      DP1DZ=(COSPHI*DPDRHO-SINPHI*DPDPHI/RHO)                           ADDGRAD   96
C                                                                       ADDGRAD   97
C     MIRROR IMAGE PRESSURE AND GRADIENTS EVALUATION                    ADDGRAD   98
C                                                                       ADDGRAD   99
      DIST2=SQRT(DIST*DIST+4.*(DEPTH-R*COSBET)*(DEPTH-RHO*COSPHI))      ADDGRAD  100
      PFACT1=PCONST/DIST2**2                                            ADDGRAD  101
      ARG2=ARG1-2.*OMEGA*(DEPTH-RHO*COSPHI)*(R+.5*DXLDTH(K,I))*SINBET   ADDGRAD  102
      P2=-(ARG2*DSDTH(K,I)/DIST2**3+OMEGA*D2SDTH(K,I)/DIST2)*PCONST     ADDGRAD  103
      DR2RHO=(DIST*DRDRHO-2.*COSPHI*(DEPTH-R*COSBET))/DIST2             ADDGRAD  104
      DR2PHI=(DIST*DRDPHI+2.*RHO*SINPHI*(DEPTH-R*COSBET))/DIST2         ADDGRAD  105
      TERM3=-((3./DIST2**2)*DSDTH(K,I)*ARG2+OMEGA*D2SDTH(K,I))          ADDGRAD  106
      TERM4=TERM2*DIST/DIST2                                            ADDGRAD  107
      DP2RHO=-PFACT1*(TERM3*DR2RHO+TERM4*(-SINARG+2.*COSPHI*SINBET))    ADDGRAD  108
      DP2PHI=-PFACT1*(TERM3*DR2PHI+TERM4*RHO*(COSARG-2.*SINPHI*SINBET)) ADDGRAD  109
      DP2DY=-(SINPHI*DP2RHO+COSPHI*DP2PHI/RHO)                          ADDGRAD  110
      DP2DZ=(COSPHI*DP2RHO-SINPHI*DP2PHI/RHO)                           ADDGRAD  111
      PFREE(I)=PFREE(I)+P1                                              PREFREE    3
      P(I)=P(I)+P1+P2                                                   ADDGRAD  112
      DPDY(I)=DPDY(I)+DP1DY+DP2DY                                       ADDGRAD  113
      DPDZ(I)=DPDZ(I)+DP1DZ+DP2DZ                                       ADDGRAD  114
   70 CONTINUE                                                          ADDGRAD  115
   80 CONTINUE                                                          ADDGRAD  116
      A=OMEGA/U                                                         PRESS     58
      DR=DRND*RO                                                        PRESS     59
      PCONST=DR        /(4.*PI)                                         PRESS     60
C                                                                       PRESS     61
C     CALCULATE PRESSURE INCREMENT DUE TO LIFT CHANGES DUE TO CAVITY    PRESS     62
C                                                                       PRESS     63
      DO 16 K=1,NRAD                                                    PRESS     64
      R=(RIND+(K-1)*DRND)*RO                                            PRESS     65
      FACTOR=R/SQRT(1.+A*A*R*R)                                         PRESS     66
      SKEW=PSKEW(K)                                                     PRESS     67
      DO 16 I=1,NPTS                                                    PRESS     72
      THETA=(I-1)*DTHETA                                                PRESS     73
      IF(CLIFT(K,I).EQ. 0.0) GO TO 16                                   PRESS     74
      DIST=SQRT(X*X+R*R+RHO*RHO-2.*R*RHO*COS(THETA+SKEW-PHI))           PRESS     75
      DRMION=FACTOR*(A*X+(RHO/R)*SIN(THETA+SKEW-PHI))/DIST**3           PRESS     76
      P1=-CLIFT(K,I)*DRMIDN*PCONST                                      ADDGRAD  117
      SINARG=SIN(THETA+SKEW-PHI)                                        ADDGRAD  118
      COSARG=COS(THETA+SKEW-PHI)                                        ADDGRAD  119
      DRDRHO=(RHO-R*COSARG)/DIST                                        ADDGRAD  120
      DRDPHI=-RHO*R*SINARG/DIST                                         ADDGRAD  121
      TERM1=(1./R)*SINARG/(DIST**3)-((A*X+(RHO/R)*SINARG)*3.*DRDRHO)/(DI ADDGRAD 122
     1ST**4)                                                            ADDGRAD  123
      TERM2=(-1./DIST**3)*((RHO/R)*COSARG+((A*X+(RHO/R)*SINARG)*3.*DRDPI ADDGRAD 124
     1I)/DIST)                                                          ADDGRAD  125
      DPLRHO=-PCONST*FACTOR*DLIFT(K,I)*TERM1                            ADDGRAD  126
      DPLPHI=-PCONST*FACTOR*DLIFT(K,I)*TERM2                            ADDGRAD  127
      DPLIDY=-(SINPHI*DPLRHO+COSPHI*DPLPHI/RHO)                         ADDGRAD  128
      DPLIDZ=(COSPHI*DPLRHO-SINPHI*DPLPHI/RHO)                          ADDGRAD  129
C                                                                       ADDGRAD  130
C     EVALUATE THE LOADING FROM THE IMAGE SOURCE                        ADDGRAD  131
```

```
      C                                                                       ADDGRAD   132
            DIST2=SQRT(DIST*DIST+4.*(DEPTH-R*COS(THETA+SKEW))*(DEPTH-RHO*COSPH ADDGRAD   133
           1I))                                                               ADDGRAD   134
            DRP1D2=FACTOR*(A*X+(RHO/R)*SIN(THETA+SKEW-PHI)+2.*SIN(THETA+SKEW)* ADDGRAD   135
           1(DEPTH-RHO*COSPHI)/R)/DIST2**3                                    ADDGRAD   136
            P2=DLIFT(K,I)*DRM1D2*PCONST                                        ADDGRAD   137
            TERM3=A*X*(RHO/R)*SINARG+2.*SIN(THETA+SKEW)*(DEPTH-RHO*COSPHI)/R   ADDGRAD   138
            DR2RHC=(DIST*DRDRHO-2.*COSPHI*(DEPTH-R*COS(THETA+SKEW)))/DIST2     ADDGRAD   139
            DR2PHI=(DIST*DRDPHI+2.*RHO*SINPHI*(DEPTH-R*COS(THETA+SKEW)))/DIST2 ADDGRAD   140
            DP2LDR=(PCONST*FACTOR*DLIFT(K,I)/DIST2**3)*((SINARG-2.*COSPHI*     ADDGRAD   141
           1SIN(THETA+SKEW))/R+TERM3*(-3.*DR2RHO/DIST2))                       ADDGRAD   142
            DP2LDP=(PCONST*FACTOR*DLIFT(K,I)/DIST2**3)*((-COSARG+2.*SINPHI*    ADDGRAC   143
           1SIN(THETA+SKEW))*RHO/R+TERM3*(-3.*DR2PHI/DIST2))                   ADDGRAD   144
            DPL2DY=-(SINPHI*DP2LDR+COSPHI*DP2LDP/RHO)                          ADDGRAD   145
            DPL2DZ=(COSPHI*DP2LDR-SINPHI*DP2LDP/RHO)                           ADDGRAD   146
            PFREE(I)=PFREE(I)+P1                                               PREFREE     4
            P(I)=P(I)+P1+P2                                                    ADDGRAD   147
            DPDY(I)=DPDY(I)+DPL1DY+DPL2DY                                      ADDGRAD   148
            DPDZ(I)=DPDZ(I)+DPL1DZ+DPL2DZ                                      ADDGRAD   149
      C                                                                        PRESS      78
   16       CONTINUE                                                           PRESS      86
            WORD2=2HE                                                          NEWFIX     28
      C                                                                        ADDGRAD   151
      C     PRINT NEW HEADING EVERY 3 GAUGES                                   ADDGRAD   152
      C                                                                        ADDGRAD   153
            IF(IPRESS .GT. 0 .OR. IPGRAD .GT. 0) GO TO 17                      FINAL1     34
            GO TO 18                                                           FINAL1     35
   17       CONTINUE                                                           FINAL1     36
            WRITE(NOUT,207)                                                    ADDGRAD   155
            WRITE(NOUT,206)N,XPT(N),RHOPT(N),PHIPT(N)                          ADDGRAD   156
            WRITE(NOUT,200)                                                    ADDGRAD   157
            WRITE(NOUT,300)                                                    ADDGRAD   158
   18       CONTINUE                                                           FINAL1     37
      C                                                                        ADDGRAD   159
      C     LOAD  PRESSURE DATA INTO WORKING ARRAY                             ADDGRAD   160
      C                                                                        ADDGRAD   161
      C                                                                        PREFREE     5
            DO 3 J=1,NPTS                                                      PREFREE     6
    3       WORK(J)=PFREE(J)                                                   PREFREE     7
            CALL FCURAN(WORK,N,WORD1,WORD2,IPRESS)                             PREFREE     8
      C                                                                        PREFREE     9
      C                                                                        PREFREE    10
            DO 4 J=1,NPTS                                                      ADDGRAD   162
    4       WORK(J)=P(J)                                                       ADDGRAD   163
            CALL FCURAN(WORK,N,WORD1,WORD2,IPRESS)                             FINAL1     38
      C                                                                        ADDGRAD   165
      C     FOURIER ANALYSIS OF THE TOTAL PRESSURE GRADIENTS                   ADDGRAD   166
      C                                                                        ADDGRAD   167
            WORD1=4HCPTO                                                       ADDGRAD   168
            WORD2=4HT/DY                                                       ADDGRAD   170
            DO 55 I=1,NPTS                                                     ADDGRAD   171
   55       WORK(I)=CPDY(I)                                                    ADDGRAD   172
            CALL FCURAN(WORK,N,WORD1,WORD2,IPGRAD)                             FINAL1     39
            WORD2=4HT/DZ                                                       ADDGRAD   174
            DO 56 I=1,NPTS                                                     ADDGRAD   175
   56       WORK(I)=CPDZ(I)                                                    ADDGRAD   176
            CALL FCURAN(WORK,N,WORD1,WORD2,IPGRAD)                             FINAL1     40
```

```
            60 CONTINUE                                                              ADDGRAD   178
               RETURN                                                                ADDGRAD   179
           22C FORMAT(//,1H )                                                        NEWFIX     29
           207 FORMAT(  24X,36HCOORDINATES FOR PRESSURE CALCULATION  /23X,38(1H+)    PRESS      88
              1 //        24X,36H  GAUGE       X          RHO/RO     PHI    /        PRESS      89
              2           24X,36H              (FT)                  (DEG)   /)      PRESS      90
           206 FORMAT(27X,I2,F11.3,F9.3,F9.3)                                        PRESS      91
           200 FORMAT(// 5X,37HTOTAL PRESSURE EXCLUDING HULL EFFECTS  )              FINAL2      2
           300 FORMAT( 16X,62H(ALL VALUES ARE (PSF) AS MEASURED AT THE GIVEN GAUG   PRESS      96
              1E LOCATION)  )                                                        PRESS      97
               END                                                                   PRESS      96
```

```
              60 CONTINUE                                                          ADDGRAD    178
                 RETURN                                                            ADDGRAD    179
             220 FORMAT(//,1H )                                                    NEWFIX      29
 175         207 FORMAT(  24X,36HCOORDINATES FOR PRESSURE CALCULATION  /23X,38(1H*) PRESS      88
                1 //        24X,36H  GAUGE       X         RHO/RO     PHI   /      PRESS      89
                2           24X,36H             (FT)                 (DEG)   /)    PRESS      90
             206 FORMAT(27X,I2,F11.3,F9.3,F9.3)                                    PRESS      91
             200 FORMAT(// 5X,37HTOTAL PRESSURE EXCLUDING HULL EFFECTS  )          FINAL2       2
 180         300 FORMAT( 16X,62H(ALL VALUES ARE (PSF) AS MEASURED AT THE GIVEN GAUG PRESS      96
                1E LOCATION)  )                                                    PRESS      97
                 END                                                               PRESS      98
```

```fortran
      SUBROUTINE SIMQ(A,B,N,KS)
C
C     THE SERVICE ROUTINE PERFORMS MATRIX INVERSION
C
      DIMENSION A(1),B(1)
C
C     FORWARD SOLUTION
C
      TOL=0.0
      KS=0
      JJ=-N
      DO 65 J=1,N
      JY=J+1
      JJ=JJ+N+1
      BIGA=0.
      IT=JJ-J
      DO 30 I=J,N
C
C     SEARCH FOR MAXIMUM COEFFICIENT IN COLUMN
C
      IJ=IT+I
      IF(ABS(BIGA)-ABS(A(IJ)))20,30,30
   20 BIGA=A(IJ)
      IMAX=I
   30 CONTINUE
C
C     TEST FOR PIVOT LESS THAN TOLERANCE (SINGULAR MATRIX)
C
      IF(ABS(BIGA)-TOL)35,35,40
   35 KS=1
      RETURN
C
C     INTERCHANGE ROWS IF NECESSARY
C
   40 I1=J+N*(J-2)
      IT=IMAX-J
      DO 50 K=J,N
      I1=I1+N
      I2=I1+IT
      SAVE=A(I1)
      A(I1)=A(I2)
      A(I2)=SAVE
C
C     DIVIDE EQUATION BY LEADING COEFFICIENT
C
   50 A(I1)=A(I1)/BIGA
      SAVE=B(IMAX)
      B(IMAX)=B(J)
      B(J)=SAVE/BIGA
C
C     ELIMINATE NEXT VARIABLE
C
      IF(J-N) 55,70,55
   55 IQS=N*(J-1)
      DO 65 IX=JY,N
      IXJ=IQS+IX
      IT=J-IX
```

```
      DO 60 JX=JY,N                                   SIMQ
      IXJX=N*(JX-1)+IX                                SIMQ
      JJX=IXJX+IT                                     SIMQ
   60 A(IXJX)=A(IXJX)-(A(IXJ)*A(JJX))                 SIMQ
   65 B(IX)=B(IX)-(B(J)*A(IXJ))                       SIMQ
C                                                     SIMQ
C     BACK SOLUTION                                   SIMQ
C                                                     SIMQ
   70 NY=N-1                                          SIMQ
      IT=N*N                                          SIMQ
      DO 80 J=1,NY                                    SIMQ
      IA=IT-J                                         SIMQ
      IB=N-J                                          SIMQ
      IC=N                                            SIMQ
      DO 80 K=1,J                                     SIMQ
      B(IB)=B(IB)-A(IA)*B(IC)                         SIMQ
      IA=IA-N                                         SIMQ
   80 IC=IC-1                                         SIMQ
      RETURN                                          SIMQ
      END                                             SIMQ
```

```
1           SUBROUTINE TRANS(ALPHA,SIGMA,CAMBER,CAVLEN,CL,CMASS,S,ALMIN,ALMAX) TRANS    2
      C                                                                        TRANS    3
      C     SUBROUTINE TRANS CALCULATES SOLUTION IN TRANSITION REGION BY       TRANS    4
      C     LINEAR INTERPOLATION VS ALPHA                                      TRANS    5
5     C                                                                        TRANS    6
             RATIO=(ALPHA-ALMIN)/(ALMAX-ALMIN)                                 TRANS    7
            CALL PARCAV(ALMIN,SIGMA,CAMBER,CAVLNP,CLP,CMASSP,SP,1)             TRANS    8
            CALL FULCAV(ALMAX,SIGMA,CAMBER,CAVLNF,CLF,CMASSF,SF,1)             TRANS    9
            CAVLEN=CAVLNP+(CAVLNF-CAVLNP)* RATIO                               TRANS   10
10          CL=CLP+(CLF-CLP)* RATIO                                            TRANS   11
            CMASS=CMASSP+(CMASSF-CMASSP)*RATIO                                 TRANS   12
            S=0.0                                                              TRANS   13
            RETURN                                                             TRANS   14
            END                                                                TRANS   15
```

```
      SUBROUTINE TRANSF                                                    TRANSF      2
C                                                                          TRANSF      3
C                                                                          TRANSF      4
C     THIS SUBROUTINE TRANSFORPS THE GRADIENTS FROM THE BODY TO THE        TRANSF      5
C     FLAT PLATE. IT ALSC SENDS THE GRADIENTS TO BE FOURIER ANALYZED       TRANSF      6
C     ANC FINALY DETERMINS THE PRESSURE DISTRIBUTION AND SECTIONAL         FINAL4     21
C     FORCES. (THE PRESSURE GRADIENTS ARE SENT BY TWO PARTS; FIRST THE     FINAL4     22
C     COSINE CCEFFICIENTS AND THEN THE SINE COEFFICIENTS. THIS IS DCNE     FINAL4     23
C     FOR EVERY HARMONIC.)                                                 FINAL4     24
C                                                                          TRANSF     10
      CCMMON/PCINTS/NPLUC,XPT(100),RHOPT(100),PHIPT(100)                   NEWFIX     30
      COMMON/SCLUT/NCCEF,PHI(100),A(1C),APAX,ICONV,NCOUNT                  NEWFIX     31
      COMMON/CCORD/YLOC(100),ZLOC(100)                                     NEWFIX     32
      COMMGN/REPRES/NPTS1,X(100),Y(10C),BEAM,DRAFT,AREA,DXSEC,GCTION       FINAL1     41
      COMMON/IDENTF/SEC                                                    FINAL4     25
      COMMON/ZERO/ YTOT(6),ZTOT(6)                                         FINAL1     42
      COMMON/CCNST/PI,RHGF,U,OMECA,DEPTH,PV,G,RAD                          FINAL1     43
      COMMON/UNITS/NIN,NCUT,DATE(5),TITLE(15)                              TRANSF     12
      COMMON/FOURIR/NBLADE,NMULT,NFORIT                                    TRANSF     13
      COMMON/DERIVT/DPDY(6,100),DPDZ(6,100),P(6,100)                       TRANSF     14
      COMMON/NCRGRD/DPDN(100),COSVAL(1CO),SINVAL(100),DPHI,NPASS,P3(10C)   NEWFIX     33
      DIMENSION SUM1(100),SERIE1(100),SERIE2(100)                          NEWFIX     34
      DIMENSION DPDSY(100),DPDETA(100)                                     NEWFIX     35
      DIMENSION PTOT1(6,100),AMPY(3),PHASEY(3),AMPZ(3),PHASEZ(3)           FINAL1     44
      DIMENSION PAMP(3,100),PPHASE(3,1C0)                                  FINAL1     45
      DIMENSION VFORCE(6),HFORCE(6),VAMP(3),VPHASE(3),HAMP(3),HPHASE(3)    FINAL5      3
C                                                                          TRANSF     18
      XDIST=-XPT(1)                                                        FINAL4     26
      NPLUC1=NPLOC-1                                                       TRANSF     19
      NMAX=NCOEF                                                           NEWFIX     36
      NCOEF1=NCOEF-1                                                       FINAL3      1
      DO 15 N=2,NMAX                                                       NEWFIX     37
      A(N)=A(N)/A(1)                                                       TRANSF     29
   15 CONTINUE                                                             TRANSF     30
C                                                                          TRANSF     31
C                                                                          TRANSF     32
C     SERIE1=1-SUM((2*(N-1)*A(N+1)*COS(2NPHI))                             TRANSF     33
C     SERIE2=SUM((2*(N-1)*A(N+1)*SIN(2NPHI))                               TRANSF     34
C                                                                          TRANSF     35
C                                                                          TRANSF     36
      PI=4.*ATAN(1.)                                                       TRANSF     37
      DPHI=-PI/(NPLOC-1)                                                   LASTFIX     2
      DO 16 K=1,NPLOC                                                      TRANSF     39
      SUM1(K)=0.0                                                          TRANSF     40
   16 SERIE2(K)=0.0                                                        TRANSF     41
      DO 25 K=1,NPLOC                                                      TRANSF     42
      DO 20 N=1,NCCEF1                                                     FINAL3      2
      CCEFF=(2*N-1)*A(N+1)                                                 TRANSF     45
      SUM1(K)=SUM1(K)+CCEFF*COS(2*N*(K-1)*DPHI)                            TRANSF     46
      SERIE2(K)=SERIE2(K)+COEFF*SIN(2*N*(K-1)*DPHI)                        TRANSF     47
   2C CONTINUE                                                             TRANSF     48
      SERIE1(K)=1.-SUM1(K)                                                 TRANSF     49
   25 CONTINUE                                                             TRANSF     50
C                                                                          TRANSF     51
C     EVALUATE GRADIENTS FOR ALL HARMCNICS                                 TRANSF     52
C                                                                          TRANSF     53
      I=1                                                                  NEWFIX     38
```

```
      DO 35 I=1,3                                                      FINAL1    46
      DO 27 JJ=1,NPLOC                                                 TRANSF    57
      SINVAL(JJ)=0.0                                                   TRANSF    58
      COSVAL(JJ)=0.0                                                   TRANSF    59
   27 CONTINUE                                                         TRANSF    60
      DPON(1)=0.0                                                      TRANSF    61
      DPON(NPLOC)=0.0                                                  TRANSF    62
C                                                                      TRANSF    64
C     EVALUATE J=1 COS COEFFICIENTS AND THEN J=2 SIN COEFFICIENTS      TRANSF    65
C                                                                      TRANSF    66
      NFIRST=1                                                         TRANSF    67
      NLAST=I+1                                                        TRANSF    68
      DO 30 J=NFIRST,NLAST                                             TRANSF    69
C                                                                      TRANSF    70
C     EVALUATE THE GRADIENTS TRANSFORMATIONS FOR ALL POINTS            TRANSF    71
C                                                                      TRANSF    72
      NPASS=J                                                          TRANSF    73
      DO 29 K=2,NPLOC1                                                 TRANSF    74
C                                                                      TRANSF    75
C     EVALUATE GRADIENTS IN CIRCLE PLANE                               TRANSF    76
C                                                                      TRANSF    77
      DPOSY(K)=A(I)*(DPDY(J,K)*SERIE1(K)-DPDZ(J,K)*SERIE2(K))          TRANSF    78
      DPOETA(K)=A(I)*(DPDZ(J,K)*SERIE1(K)+DPDY(J,K)*SERIE2(K))         TRANSF    79
C                                                                      TRANSF    80
C     EVALUATE GRADIENT IN FLAT PLATE PLANE                            TRANSF    81
C                                                                      TRANSF    82
      ALPHA=COS((K-1)*DPHI)                                            TRANSF    83
      DPON(K)=DPOETA(K)-DPOSY(K)*ALPHA/SQRT(1.-ALPHA*ALPHA)            TRANSF    84
   29 CONTINUE                                                         TRANSF    86
      CALL PROIST                                                      TRANSF    87
C                                                                      NEWFIX    39
C     EVALUATE THE TOTAL FORCE ON THE SECTION                          NEWFIX    40
C                                                                      NEWFIX    41
      YFORCR=0.0                                                       NEWFIX    42
      YFORCL=0.0                                                       NEWFIX    43
      ZFORCR=0.0                                                       NEWFIX    44
      ZFORCL=0.0                                                       NEWFIX    45
      INDEX=(NPLOC1/2)+1                                               NEWFIX    46
      INDEX1=INDEX-1                                                   NEWFIX    47
      DO 40 M=1,INDEX1                                                 NEWFIX    48
      PTOT1(J,M)=P(J,M)+P3(M)                                          FINAL1    47
      PTOT2=P(J,M+1)+P3(M+1)                                           NEWFIX    50
      PAVE=(PTOT1(J,M)+PTOT2)/2.0                                      FINAL1    48
      ZFORCR=ZFORCR+ABS(YLOC(M+1)-YLOC(M))*PAVE                        NEWFIX    53
      YFORCR=YFORCR+ABS(ZLOC(M+1)-ZLOC(M))*PAVE                        NEWFIX    54
   40 CONTINUE                                                         NEWFIX    56
      DO 45 M=INDEX,NPLOC1                                             NEWFIX    57
      PTOT1(J,M)=P(J,M)+P3(M)                                          FINAL1    49
      PTOT2=P(J,M+1)+P3(M+1)                                           NEWFIX    59
      PAVE=(PTOT1(J,M)+PTOT2)/2.0                                      FINAL1    50
      YFORCL=YFORCL+ABS(ZLOC(M+1)-ZLOC(M))*PAVE                        NEWFIX    62
      ZFORCL=ZFORCL+ABS(YLOC(M+1)-YLOC(M))*PAVE                        NEWFIX    63
   45 CONTINUE                                                         NEWFIX    65
      YFORCE=YFORCL-YFORCR                                             NEWFIX    66
      ZFORCE=ZFORCR+ZFORCL                                             NEWFIX    67
      YTOT(J)=YTOT(J)+YFORCE                                           FINALE     3
      ZTOT(J)=ZTOT(J)+ZFORCE                                           FINALE     4
```

```
      VFORCE(J)=VFORCE(J)+YTOT(J)*DXSEC*GCTION                            FINAL6     5
      HFORCE(J)=HFORCE(J)+ZTOT(J)*DXSEC*GCTION                            FINAL6     6
   30 CONTINUE                                                             TRANSF    88
      PAMP(L,1)=0.0                                                        FINAL1    53
      PPHASE(L,1)=0.0                                                      FINAL1    54
      PAMP(L,NPLOC)=0.0                                                    FINAL1    55
      PPHASE(L,NPLOC)=0.0                                                  FINAL1    56
      DO 31 M=2,NPLOC1                                                     FINAL1    57
      PAMP(L,M)=SQRT(PTOT1(NFIRST,M)*PTOT1(NFIRST,M)+PTOT1(NLAST,M)*PTOT  FINAL1    58
     1(NLAST,M))                                                           FINAL1    59
      PPHASE(L,M)=ATAN2(PTOT1(NLAST,M),PTOT1(NFIRST,M))*RAD                FINAL1    60
   31 CONTINUE                                                             FINAL1    61
      AMPY(L)=SQRT(YTOT(NFIRST)*YTOT(NFIRST)+YTOT(NLAST)*YTOT(NLAST))      FINAL1    62
      IF(YTOT(NLAST).EQ.0.0 .AND. YTOT(NFIRST).EQ.0.0) GO TO 62            FINAL4    27
      PHASEY(L)=ATAN2(YTOT(NLAST),YTOT(NFIRST))*RAD                        FINAL1    63
      GO TO 32                                                             FINAL4    28
   62 PHASEY(L)=0.0                                                        FINAL4    29
   32 AMPZ(L)=SQRT(ZTOT(NFIRST)*ZTOT(NFIRST)+ZTOT(NLAST)*ZTOT(NLAST))      FINAL4    30
      IF(ZTOT(NLAST).EQ.0.0 .AND. ZTOT(NFIRST).EQ.0.0) GO TO 63            FINAL4    31
      PHASEZ(L)=ATAN2(ZTOT(NLAST),ZTOT(NFIRST))*RAD                        FINAL1    65
      GO TO 33                                                             FINAL4    32
   63 PHASEZ(L)=0.0                                                        FINAL4    33
   33 IF(SEC .GE. 0.0) GO TO 39                                            FINAL5     8
      VAMP(L)=SQRT(VFORCE(NFIRST)*VFORCE(NFIRST)+VFORCE(NLAST)*            FINAL5     9
     1VFORCE(NLAST))                                                       FINAL5    10
      IF(VFORCE(NLAST).EQ.0.0 .AND. VFORCE(NFIRST).EQ.0.0) GO TO 64        FINAL5    11
      VPHASE(L)=ATAN2(VFORCE(NLAST),VFORCE(NFIRST))*RAD                    FINAL5    12
      GO TO 34                                                             FINAL5    13
   64 VPHASE(L)=0.0                                                        FINAL5    14
   34 HAMP(L)=SQRT(HFORCE(NFIRST)*HFORCE(NFIRST)+HFORCE(NLAST)*            FINAL5    15
     1HFORCE(NLAST))                                                       FINAL5    16
      IF(HFORCE(NLAST).EQ.0.0 .AND. HFORCE(NFIRST).EQ.0.0) GO TO 65        FINAL5    17
      HPHASE(L)=ATAN2(HFORCE(NLAST),HFORCE(NFIRST))*RAD                    FINAL5    18
      GO TO 39                                                             FINAL5    19
   65 HPHASE(L)=0.0                                                        FINAL5    20
   39 I=I+2                                                                FINAL5    21
   35 CONTINUE                                                             TRANSF    90
      III=NBLADE                                                           FINAL1    66
      II2=III+III                                                          FINAL1    67
      II3=II2+III                                                          FINAL1    68
      XSEC=ABS(SEC)                                                        FINAL6     7
      WRITE(NOUT,130) XSEC,XDIST                                           FINAL6     8
      WRITE(NOUT,140) III,II2,II3                                          FINAL1    70
      WRITE(NOUT,150)                                                      FINAL1    71
      WRITE(NOUT,160)                                                      FINAL1    72
      DO 41 I=1,NPLOC                                                      FINAL1    73
      WRITE(NOUT,170) I,XPT(I),YLOC(I),ZLOC(I),(PAMP(L,I),PPHASE(L,I),    FINAL1    74
     1L=1,3)                                                               FINAL1    75
   41 CONTINUE                                                             FINAL1    76
      WRITE(NOUT,180) XSEC,XDIST                                           FINAL6     9
      WRITE(NOUT,190)                                                      FINAL1    78
      WRITE(NOUT,200)                                                      FINAL1    79
      J=1                                                                  FINAL1    80
      DO 50 L=1,3                                                          FINAL1    81
      LL=L*NBLADE                                                          FINAL1    82
      WRITE(NOUT,210) LL,YTOT(J),YTOT(J+1),AMPY(L),PHASEY(L),ZTOT(J),     FINAL1    83
     1ZTOT(J+1),AMPZ(L),PHASEZ(L)                                          FINAL1    84
```

```
      J=J+2                                                            FINAL1     85
   50 CONTINUE                                                         FINAL1     86
      IF(SEC .GE. 0.0) RETURN                                          FINAL5     22
C                                                                      FINAL5     23
C                                                                      FINAL5     24
C     PRINT TOTAL FORCES RESULTS                                       FINAL5     25
C                                                                      FINAL5     26
      WRITE(NOUT,185)                                                  FINAL5     27
      WRITE(NOUT,190)                                                  FINAL5     28
      WRITE(NOUT,200)                                                  FINAL5     29
      J=1                                                              FINAL5     30
      DO 51 L=1,3                                                      FINAL5     31
      LL=L*KBLADE                                                      FINAL5     32
      WRITE(NOUT,210) LL,VFORCE(J),VFORCE(J+1),VAMP(L),VPHASE(L),      FINAL6     10
     1HFORCE(J),HFORCE(J+1),HAMP(L),HPHASE(L)                          FINAL6     11
      J=J+2                                                            FINAL5     35
   51 CONTINUE                                                         FINAL5     36
      RETURN                                                           NEWFIX     70
  130 FORMAT(1H1,//5X,42HTHE FOLLOWING ARE THE RESULTS FOR SECTION ,   FINAL4     37
     1F5.2,9H LOCATED ,F10.3,28H FT FORWARD OF THE PROPELLER/3X,99(1H*), FINAL4   38
     2//,44X,25HP  R  E  S  S  U  R  E  S/40X,17(2H**))               FINAL4     39
  140 FORMAT(//,26X,21HC O O R D I N A T E S,15X,2(12HHARMONIC NO ,I2, FINAL1     88
     111X),12HHARMONIC NO ,I2)                                         FINAL1     89
  150 FORMAT(//,4X,8HLOCATION,9X,1HX,12X,1HY,12X,1HZ,9X,3(25HAMPLITUDE FINAL1     90
     1   PHASE       ))                                                FINAL1     91
  160 FORMAT(19X,3(4H(FT),9X),1X,2(5H(PSF),7X,5H(PSF),8X),5H(PSF),7X,  FINAL1     92
     15H(PSF)//)                                                       FINAL1     93
  170 FORMAT(7X,I2,5X,F10.3,8(3X,F10.3))                               FINAL2      3
  180 FORMAT(1H1,//5X,42HTHE FOLLOWING ARE THE RESULTS FOR SECTION  ,  FINAL4     40
     1F5.2,9H LOCATED ,F10.3,28H FT FORWARD OF THE PROPELLER/3X,99(1H*), FINAL4   41
     2//72X,16HF  O  R  C  E  S//71X,9(2H**))                          FINAL4     42
  185 FORMAT(1H1,//35X,34HT O T A L    S H I P    F O R C E S /,34X,36(1H* FINAL5  37
     1))                                                               FINAL5     38
  190 FORMAT(//,43X,13HL A T E R A L,43X,15HV E R T I C A L)           FINAL1     96
  200 FORMAT(//,13X,8HHARMONIC,5X,47HREAL PART      IMAG PART      APPLITU FINAL1  97
     1DE      PHASE ,10X,47HREAL PART      IMAG PART      APPLITUDE      PHA FINAL1 98
     2SE //)                                                           FINAL1     99
  210 FORMAT(16X,I2,5X,F10.2,5X,F10.2,4X,F10.2,5X,F6.1, 9X,F10.2,3X,F10. FINAL2    4
     12,4X,F10.2,5X,F6.1)                                              FINAL2      5
      END                                                              TRANSF     98
```

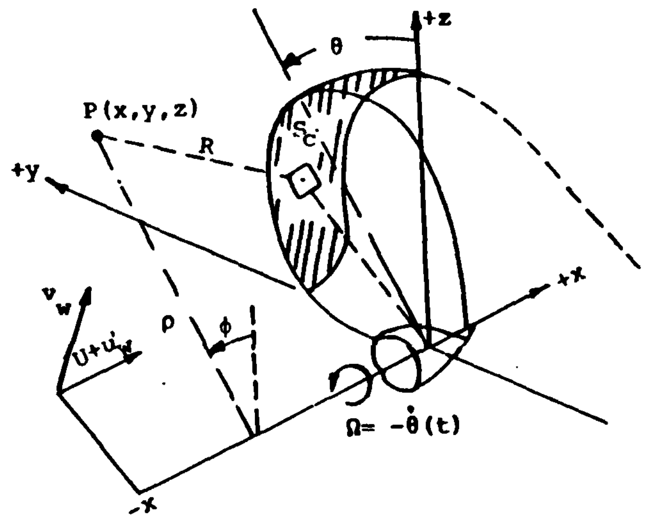

Figure 1 Coordinate definition

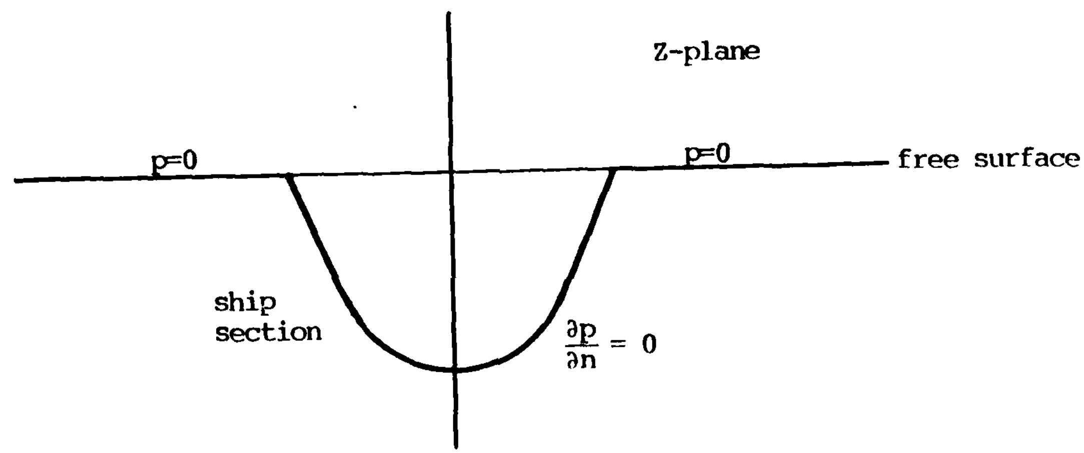

Figure 2   Boundary value problem in physical plane

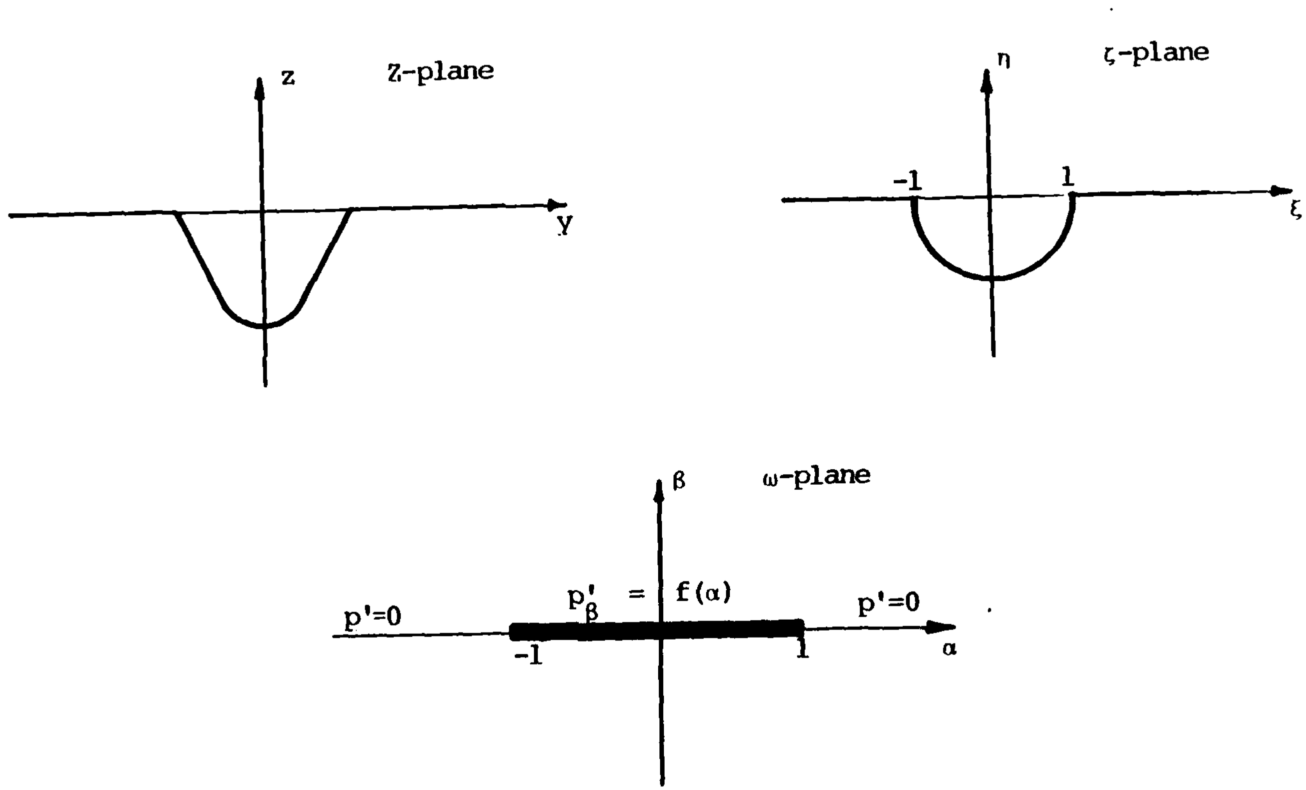

Figure 3 Conformal mappings and mixed boundary value problem

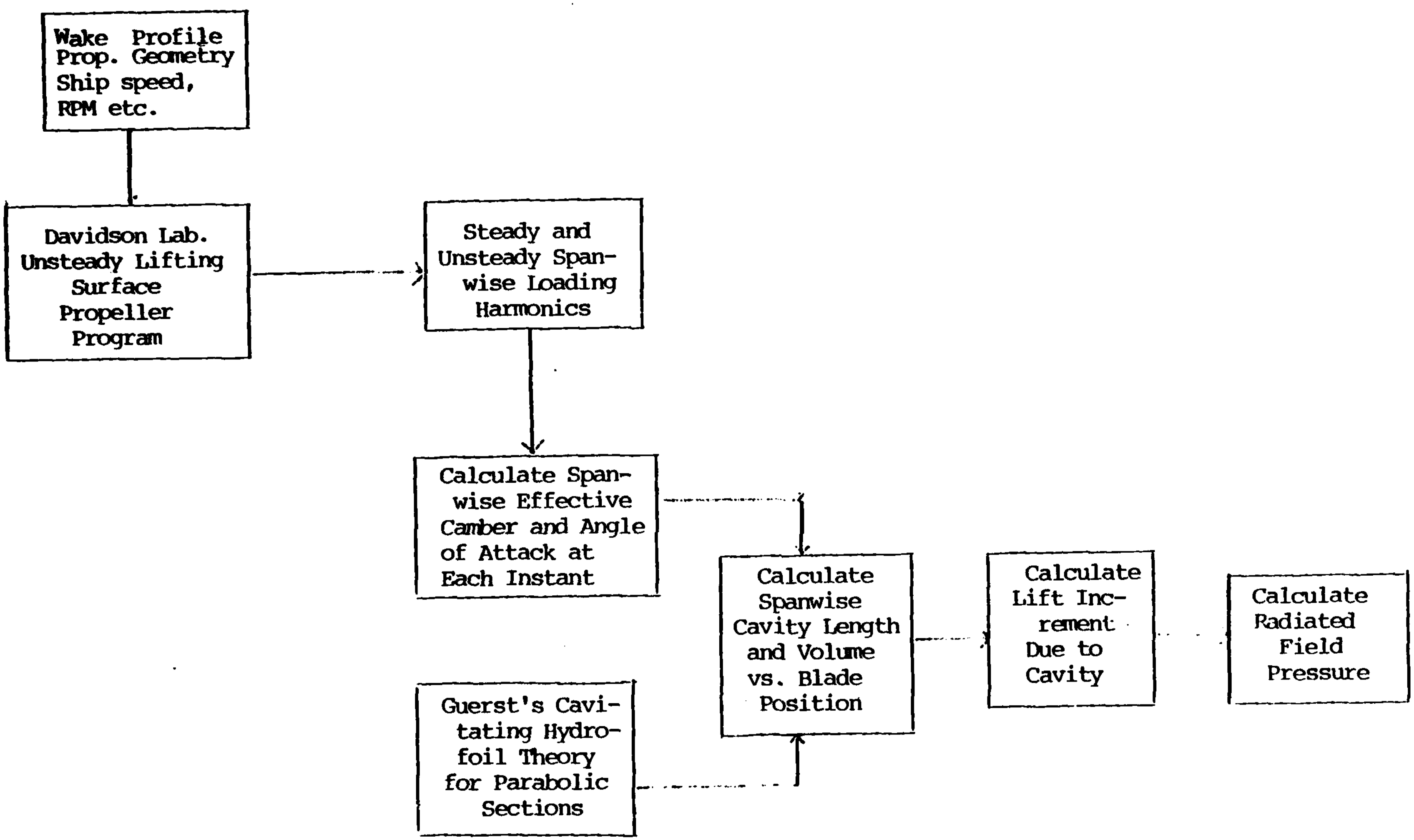

Figure 4 Computational proceedure for cavitation program

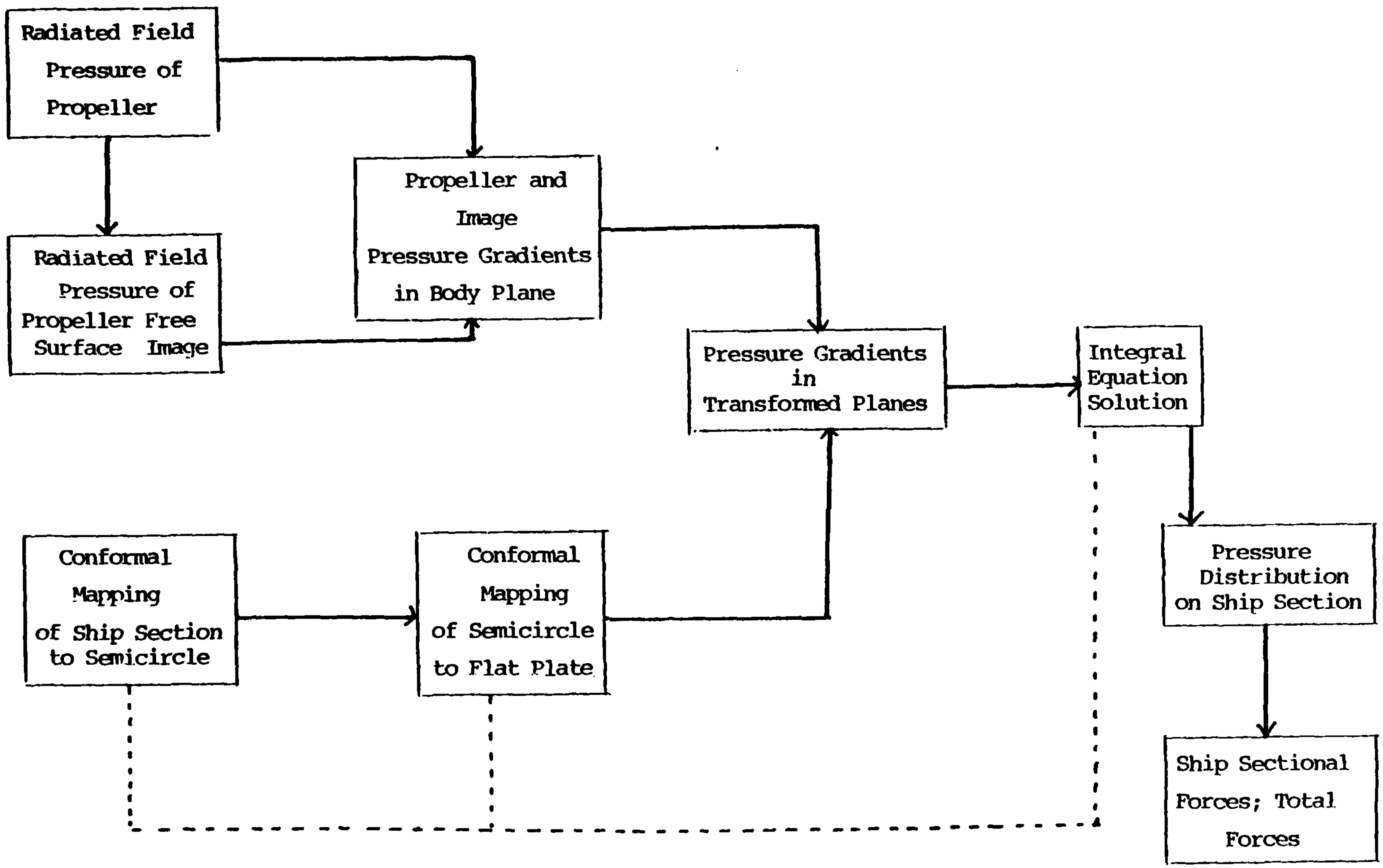

Figure 5 Computational procedure for determining pressure distribution and forces

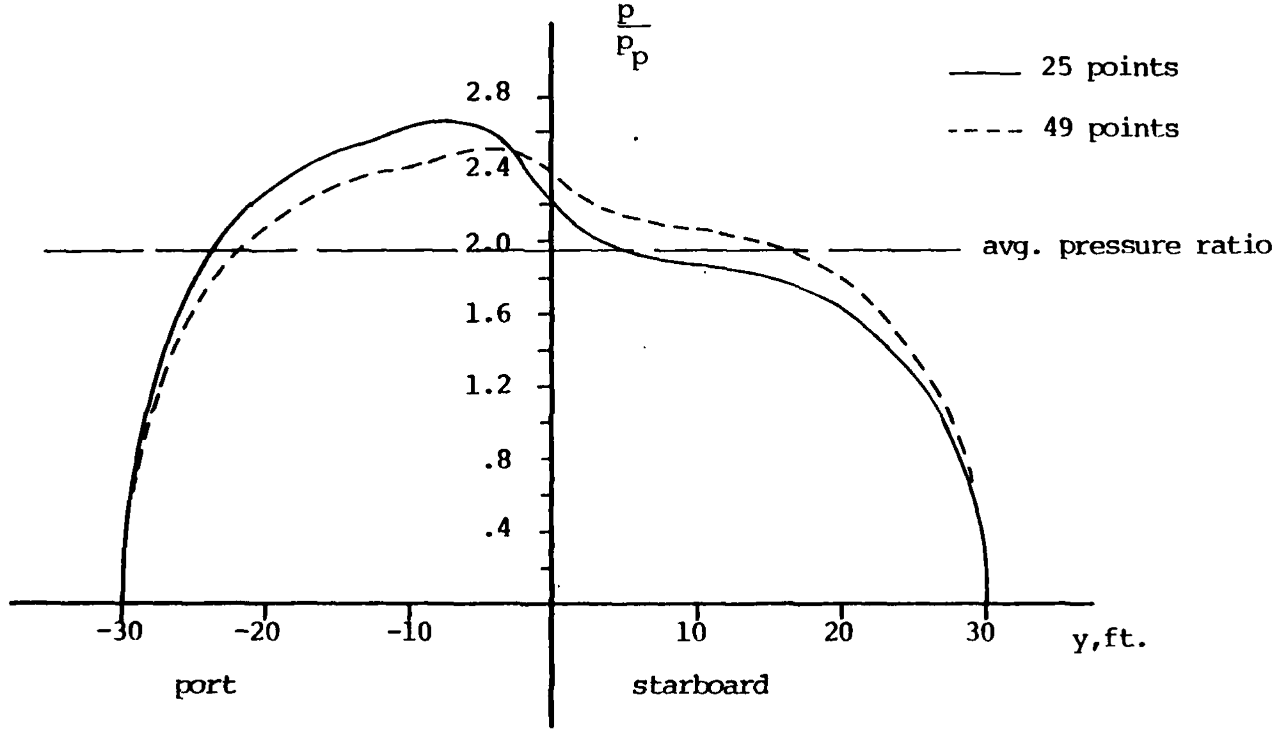

Figure 6 Variation of pressure relative to local propeller free space pressure on 60 ft. width flat plate, flow field due to AO-177 propeller in wake with fins, x=5 ft. location

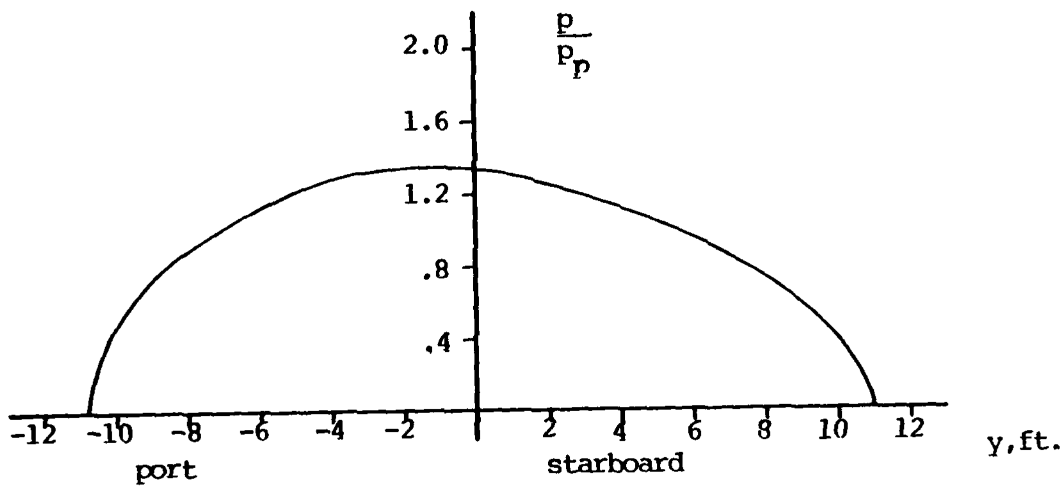

Figure 7 Variation of pressure relative to local propeller free space pressure on 21.6 ft. width plate plate, flow field due to AO-177 propeller in wake with fins, x=5 ft. location

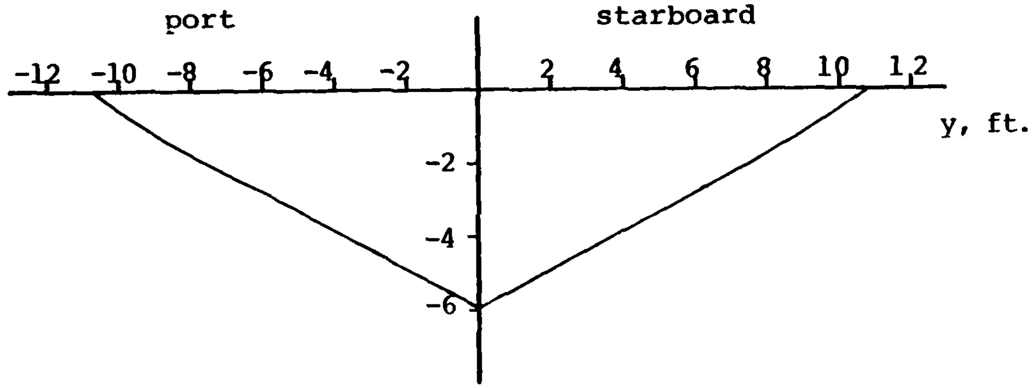

Figure 8 Section shape of AO-177 at Station 19.5

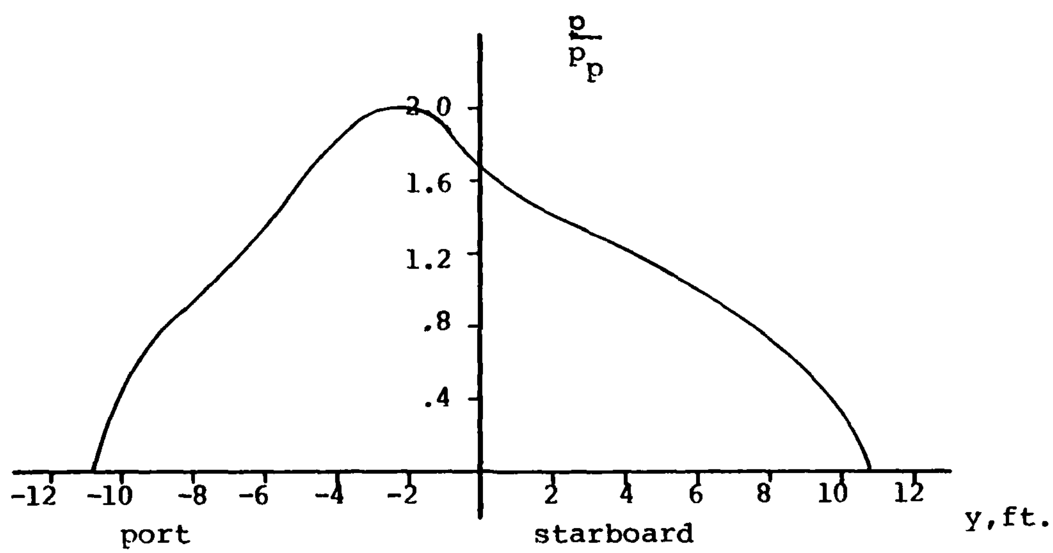

Figure 9 Variation of pressure relative to local propeller free space pressure along ship section corresponding to AO-177 Station 19.5, flow field due to AO-177 propeller in wake with fins, x=5ft. location

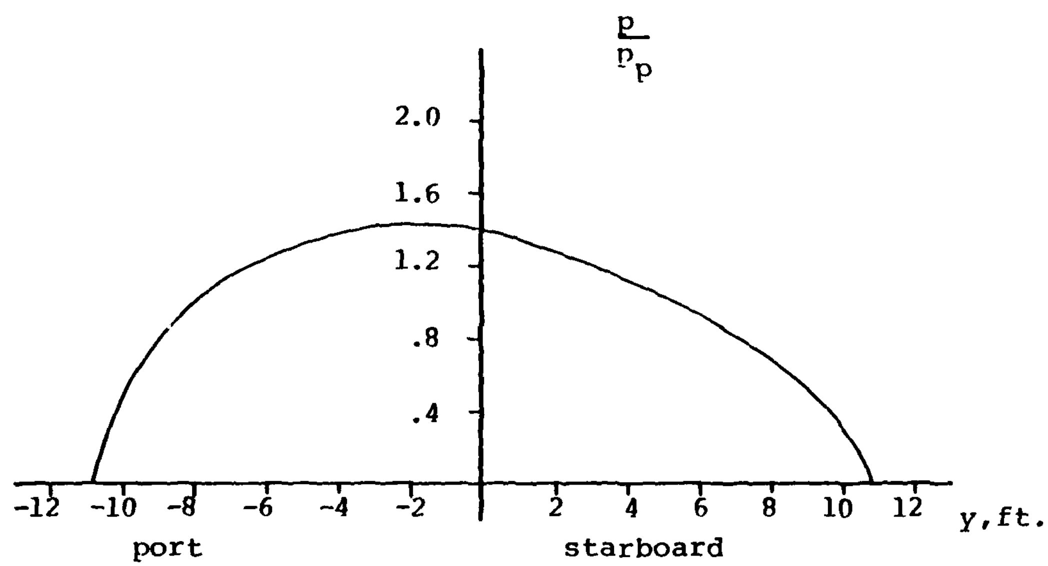

Figure 10 Variation of pressure relative to local propeller free space pressure along ship section corresponding to AO-177 Station 19.5, flow field due to AO-177 propeller in ship wake, x=-6 ft. location

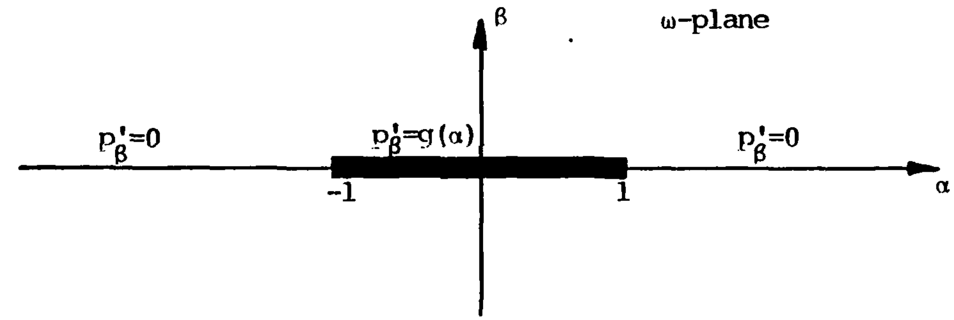

Figure 11   Boundary value problem in transformed ω-plane for free surface rigid wall condition

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